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The Quebec Bridge Disaster.

THE report of the Royal Commission appointed by the Canadian Government to inquire into the cause of failure of the Quebec Bridge on the 29th of August, 1907, has now been published, and a summary of it will be found on another page. It is a complete and instructive document and bears evidence that the three eminent Canadian engineers comprising the Commission made a thorough and impartial use of the powers with which they were invested. The inquiry was full and minute, and in arriving at their conclusion they sought the co-operation of some of the foremost bridge experts of America.

The Commissioners' findings as to the cause of the disaster are those to which all thoughtful members of the profession have already arrived, and are stated boldly without ambiguity or doubt on any point covered. The design of the lower chord members was defective, due to errors of judgment on the part of Mr. Theodore Cooper, the consulting engineer, and of Mr. Szlapka, the designing engineer of the Phœnix Bridge Company; the unit stresses were placed too high, which is equivalent to the factor of safety being too small, and mistakes were made in estimating the dead load.

The immediate cause of the collapse was the buckling of the lower chord compression members of the south anchor arm. This it will be remembered consisted of four web plates 54 in. deep interconnected, to make up a member $5\frac{1}{2}$ ft. wide, by light lattice bars riveted across at top and bottom.

It is definitely known that at least one of these segments showed signs of buckling a week before the disaster, and it speaks for itself that an exact model to the scale of one-third made and tested for the Commission failed at about 18,000 lb. per sq. in.—practically the same compressive stress at which the failure of the lower chord members themselves took place. A further similarity existed in the manner of failure, namely, by shearing of the lattice rivets. These facts leave little doubt as to the cause of failure.

Sharp criticism is passed by the Commissioners on a grave error made by the designers in assuming too low a value in calculating the dead load and not afterwards verifying the computations. In the original design of the Phœnix Bridge Company, the span had been fixed at 1,600 ft.; but on Mr. Cooper being appointed consulting engineer, he increased this to 1,800 ft., to clear the piers from ice "shoves," an abundance of which occur every spring time.

In so doing, with the object, it is presumed, of economising material, a large and injudicious increase was made

in the unit compressive stresses. This only served to intensify the error made in under-estimating the dead load, as thereby, even the exceptionally high unit stresses adopted would have been exceeded in the completed structure. The calculated concentrations assumed in the design were as follow:—

Anchor arm	13,317,600 lbs.
Cantilever arm	13,205,200 „
Half-suspended span	4,842,000 „

The actual weights determined from the finished parts were:

Anchor arm	17,318,300 lbs.
Cantilever arm	15,804,000 „
Half-suspended span	5,694,000 „

Referring to these discrepancies the report says, "The difference between the two sets of concentrations indicate a fundamental error in the calculations for the bridge. In a properly computed bridge the assumed dead load concentrations upon which the make-up of the members is based should agree closely with the weight computed from the dimensions in the finished design and with the actual weights."

In spite of this discrepancy it does not appear that either Mr. Cooper or Mr. Szlapka considered a recalculation necessary. Indeed, right along the line the former does not appear to have checked over details in any way thoroughly, and not even the large—almost unprecedented—quantities involved awakened any idea of the necessity of corroboration. Mr. Cooper has explained that his remuneration would not cover the expenditure involved in checking the calculations thoroughly and owing to poor health, age and pressure of work, he was not able to even visit the bridge site. Consequently his interest in both design and erection of the structure would appear to have been only general and passive, and would not be sharpened by the full confidence he possessed in Mr. Szlapka's ability and accuracy, for he had known him and the quality of his work for a long time.

This lack of interest can hardly be held to square with his position of supreme authority, or of his undoubted knowledge of the difficulties involved, and no matter how disinclined he may have been to attach himself to the project, his taking up the position finally called for an independent and thorough going computation of stresses and sections, if not by himself then by some one approved by him.

Another surprising circumstance bearing on the lack of corroboration secured for the computations is that the frequent comparison made of the Forth Bridge with the Quebec structure did not awaken a sense of the disproportion between them in stiffness and weight, and so inspire a desire to make certain—doubly certain—of their ground. In the Forth Bridge the main compression members are steel tubes, 12 ft. in diameter, while the outside dimensions of the struts in the St. Lawrence structure are only $4\frac{1}{2}$ ft. by $5\frac{1}{2}$ ft. over all and are consequently much less stiff. The steel used in the former has a strength of 34 to 37 tons per sq. in., the maximum to which the compression members are stressed being $7\frac{1}{2}$ tons per sq. in. In the Quebec bridge the steel has a strength of 28 tons, the strain sheet showing this to be stressed to as much as $14\frac{1}{2}$ tons per sq. in., a loading suspiciously high for safe and judicious construction. Practice had already, in the United States, run working compressive stresses up to 24,000 lbs. per sq. in., but only in cases of infrequent loading or where there are several railway lines and ordinary roadways the concurrent loading of all of which would be impossible.

If an extenuation is to be found for the errors of commission in the design of the compression members, it is, as the report points out, to be found in the fact that "professional knowledge of the present day concerning the action of steel columns under load is not sufficient to enable engineers to economically design such a structure as the Quebec Bridge." The truth of this largely depends upon the definition of the word "economically." If by that term is meant that it was impossible to construct a safe bridge of the span contem-

plated with the funds at disposal, then it is true. But the real issue is the price of material; given that that is satisfactory, surely adequate methods could be found of designing even steel columns with a fair degree of approximation to a given carrying capacity. Anyway, perhaps the obvious course for the engineers to have taken under the circumstance was to have discarded the box type and to use well-stiffened large tubes. This, however, would have involved a departure from the American method of bridge-building on the pin connected system, in which bridge manufacture and not bridge-building is the keynote, the main object being to manufacture as many of the parts as possible complete at the works, leaving only the process of jointing to be done at the site.

The general impression produced by the report is that the true cause of the disaster is, after all, the American method of construction, not only with its conception of lightness carried to an extreme, but also an exaggerated confidence in formulæ, at the expense even of the lessons of practical experience. Empirical formulæ for compression members have been applied to designs beyond the scope of experiment or inference, and one fruitful result of the catastrophe will be that a comprehensive experimental investigation with full size struts will be taken up.

The report is an example of fairness, and in exempting the contractors from any blame as regards workmanship and quality of material, recognises that "the ability of the two engineers was tried in one of the most difficult professional problems of the day and proved to be insufficient for the task."

Electric Propulsion on Canals.

The problem of transport on the inland waterways of the United Kingdom that the members of a Royal Commission appointed some time ago are still engaged upon, should not, with the achievement of France, Germany and the United States before them, be difficult of solution. In each of those countries experiments on a large scale have been conducted with electrical systems of haulage with eminently satisfactory results, and already in France the traction system is stated to be in successful commercial operation.

Progress in this direction has been recorded from time to time in the electrical section of THE ENGINEERING REVIEW, and this month some further important details are given of experiments carried out on the Lehigh Canal, Pennsylvania, which conclusively show that the cost of the transportation of goods by up-to-date electrical methods is a mere fraction of the cost by other mechanical or horse systems.

With current at one penny per unit—a charge for power common enough in this country—it appears that the cost of hauling a train of loaded barges works out at about ·012*d.* per ton mile; that of hauling an empty barge ·08*d.* per ton mile.

These experiments were made both with mining type locomotives and proportional tractors, which are well enough for long distance haulage, but for short hauls and where many barges are to be handled there would appear to be a case for the storage-battery system. This has been tried on the Berlin-Brandenburg Canal with such success that 112 additional vessels are to be added to the seven originally so equipped. A speed of three miles per hour is maintained, and, conjoined with the fact that the latest appliances have been provided for loading and unloading, a reduction of 75 per. cent is shown on the time required for the round trip by animal traction. The cost of a single charge of the batteries, which is sufficient to propel a barge for fifty miles, is stated to be 25*s.*

Thus there are ample facts to point the way of development for British canals, and it is to be hoped that the near future may bring about a revival in a useful and economical method of transport.

Recent Developments in Machine Tool Design.

By JOSEPH G. HORNER, A.M.I.Mech.E.

In this article the author discusses the influences that have operated during recent years to modify the design and construction of machine tools. The growing demand for increased accuracy; the desire to increase output and at the same time to prolong the capacity for wear would appear to be the most important.

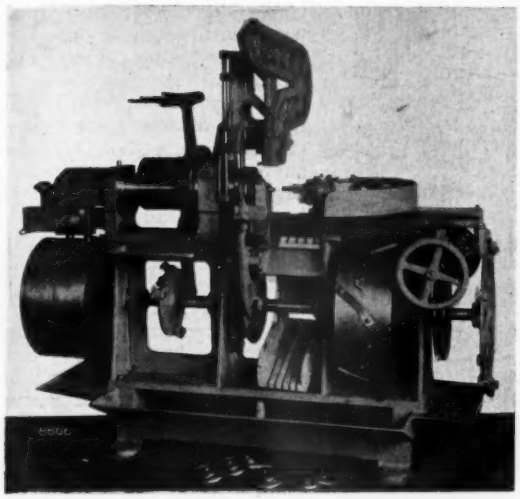
As the Irishman's explanation of casting cannon was that the metal was poured round a hole, so we may say that the machine circles round the tool. The beginnings of the long evolution occurred when man first hafted his stone celts and hammer stones. The first machine tool was the fire drill, followed by fiddle drills, and then by rude Eastern lathes of dead centre and cord type. But, as we understand the term in its most comprehensive meaning now, a machine tool is one in which both the work and the operating tool are rigidly held, and coerced in and by the mechanism of the machine. The exceptions to this definition are few, and occur chiefly in the light hand lathes and drills.

Very early in the history of all machine tools there came a time when the duty imposed upon them was increased, with the result that the process of stiffening up began, a development which has continued steadily to the present day. This is element number one in design.

Again, in its first stages, the machine tool, though much in advance of hand tools in regard to the production of uniform results, met with dissatisfaction because the demands made upon it became more exacting. Imperfection was manifested in many ways, but chiefly in the mutual fitting of surfaces. In hand work one surface could always be made to fit another by a process of mutual accommodation. In the case of work produced by machine this was no longer possible, but, on the contrary, error when present would often be in opposite directions, and therefore doubled. Illustrations would occur in turned and planed work, and in screws and their nuts. Hence we have the ever-growing demand for increasing accuracy, and this has not only resulted in improvements and modifications in the build of machines, but also in the development or invention of new machines and methods, as that of grinding and milling in some classes of operations.

The desire to increase the output of machines has also affected design in many ways, culminating in the purely automatic types, several of which are easily put in charge of one attendant. The story is a long one, for it includes many points in sub-design, such as provision for changes in speeds and feeds, and other movements, effected rapidly and with precision, with little or no trouble on the part of the attendant. Another growth in design has been that of increase in the number of tools operating in a single machine, either simultaneously or in rapid succession. Here we have our third element, and one which is illustrated in myriads of ways in modern machine tools.

Another element is that of durability, permanence, retention of accuracy, prolonged capacity for wear. Here the advance made has perhaps not been so great as in the other details mentioned, but it has, exceptional cases excluded, been marked in a general all-round improvement in the practice of machine tool makers, due largely to the use of hardened and ground fittings. Let us look at these in turn.



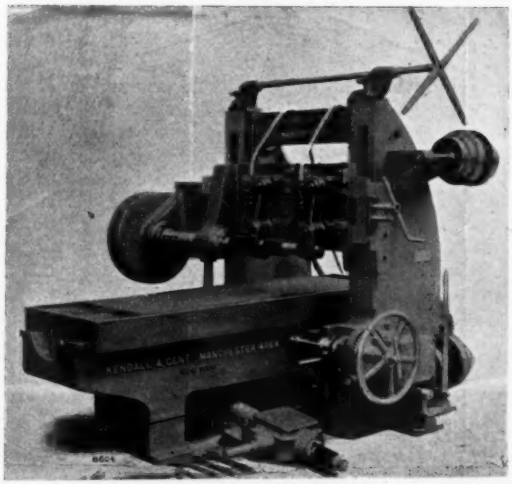
AUTOMATIC SCREW MACHINE, HAVING FRAMING OF RIBBED FORM.

THE PROCESS OF STIFFENING UP MACHINE TOOLS.

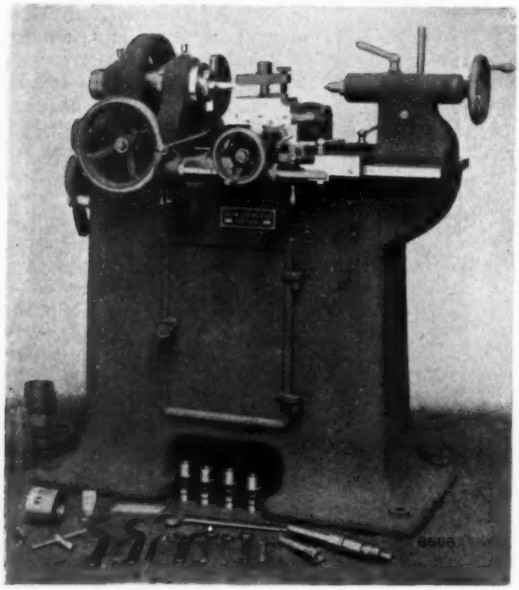
This is one of the most obvious advances made in machine tool design, and the feature which is generally referred to is the substitution of the boxed for the webbed and ribbed framing, and of the massing of metal in greater quantity than was formerly done. Another aspect of this lies in the enlargement of spindles, the increase in the size and length of spindle journals and bearings, and in the more adequate support afforded to tools and work with a view of lessening vibration.

The boxed system is adopted not only in main frames, but in secondary parts, as in the housings of planing machines, drilling machines, and vertical boring mills, in the cross stretchers of the beds of planing machines, and lathes, in the cross rails of some machines of the planer model, and even in small brackets which carry the bearings of shafts. Metal is thus distributed away from the neutral axis, and in the most economical fashion, and vibration is reduced to practically nothing. The heavy appearance which such a design would produce is masked by the custom of imparting large radii to the edges, and large curves to the meeting angles. Such designs have a pleasing appearance, and from the æsthetic point of view they harmonise with cast iron far better than some of the early monstrosities in design which were modelled architecturally after work produced in stone.

Another feature is that practice is divided between bolting a number of separate parts together, and casting large and intricate masses in one. It is claimed that the latter is more rigid, and less liable to vibration and change of form than when bolts are freely used to unite the separate members. This is open to question, for when parts are united with turned bolts



PLANO-MILLING MACHINE HAVING UPRIGHTS OF ENCLOSED BOX TYPE, SUPPORTS ON SIDE FOR ARBOR.



BACKING OFF LATHE, WITH BED, HEADSTOCK AND BASE CAST IN ONE PIECE.

in long reamered holes, and when the joint is reinforced with tongues or checks, it becomes practically a solid mass. All the same it is desirable to cast parts together if nothing else is sacrificed thereby, though the cost of possible repairs would be increased by the practice. Among such examples may be noted the practice of casting a top stretcher, or a fixed cross rail in one with the housings of some milling machines, and of some vertical boring mills; the casting of the heads of many face lathes in one with their beds, casting the feet of heavy lathes in one with their beds, casting the beds of slotting and milling machines in one with their standards, and others of a similar character.

A feature which is conducive to rigidity is the increase in the area of sliding and bearing surfaces, as those of the heads of drilling, planing, and milling machines, of spindle slides, and the increase in length given to journal bearings, and in the better provision which is now made than formerly for taking up wear and backlash.

Another development is that the ends of arbors are braced efficiently instead of being unsupported, or insufficiently braced at the outer ends. In heavy vertical-spindle machines, a bracket is brought out to carry the lower end. In most horizontals of the pillar and knee type the overhanging arm is supplemented by bracing to the knee. In some of the Lincoln millers, and in many of the heavier plano-millers support is afforded at the centre of a long arbor as well as at the head and tail ends.

In the later drilling machines the spindle slide is adjustable, and is brought down along with the spindle to support it to the extreme limits of its vertical traverse. In the snout boring machines the spindles are made of very large diameter to be self-sustaining under the heaviest cuts at their farthest distance away from their bearings.

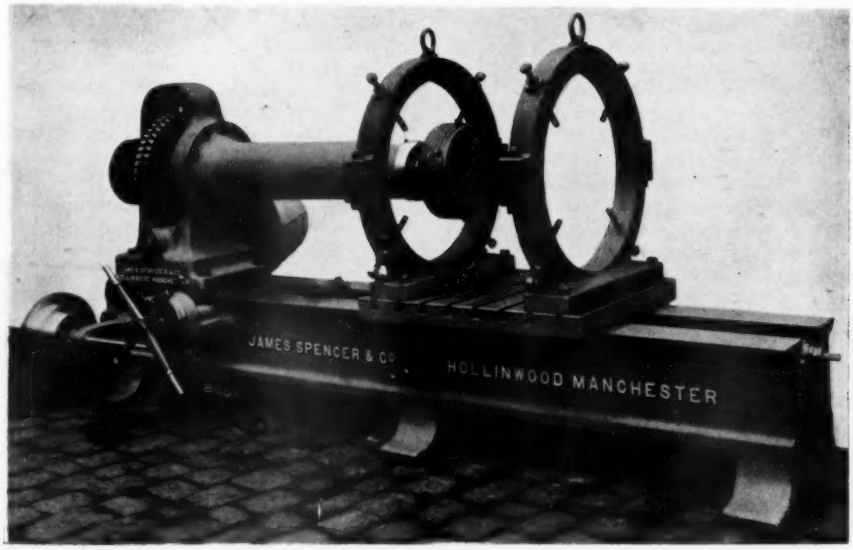
The semi-parabolic form of arm is employed to a greater extent than formerly. A few years since it was scarcely in evidence. Now it is fitted on many radial drills, taking the place of the old parallel arm, and also in open-side planers, and milling machines. In addition, the metal is often removed along the neutral axis, while the top edge is frequently deeply ribbed, an instance among many of the growing care which is taken to distribute metal to correspond with the nature and intensity of the stresses imposed.

THE GROWING DEMAND FOR INCREASED ACCURACY.

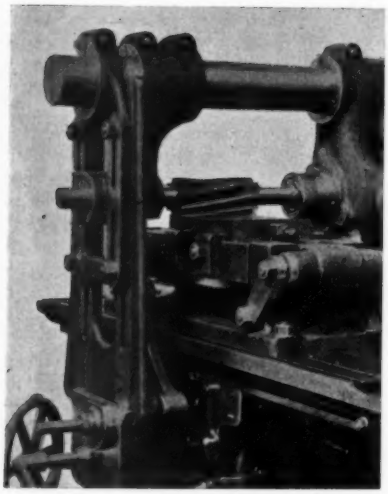
In some aspects, this second condition is closely related to the first, but only to a partial extent. Mass, and judicious distribution of metal alone

would not ensure freedom from vibration and chatter. But when these are combined with accurate construction, and provision for its retention for a long period, we have an ideal machine tool. Thus, the increase in the area of slides and bearings of all kinds in modern machine tools, combined with the provisions that are made for taking up wear, are examples of mass and accuracy combined. But beyond these there is a vast amount of detail in good machines, the sole object in which is to secure a higher degree of accuracy than formerly obtained. These would fall naturally under two heads, excellence of fitting, and provisions for the retention of the same; and devices for facilitating the setting of work and of tools. This has influenced the manufacture of nearly all machine tools, but some to a greater extent than others; notably milling machines, gear cutters, screw machines, and grinding machines, in which provision is embodied not only for the production of very fine results, but also for their measurement to some fractional part of a thousandth of an inch. These results are only possible by the employment of suitable metals or alloys, by the best possible mutual fitting of parts, by the amplest provision for taking up minute amounts of wear, and the cutting of fine and accurate graduations on scales and circles.

An important element also in the problem of durability is the thorough hardening of many sections which were formerly left soft, or simply case-hardened with the merest film of steely surface. Another is the common employment of ball thrusts to both horizontal and vertical spindles, in which the balls and their races are hardened. These, and the grinding machines by which the employment of such methods, formerly impracticable, are not only rendered possible but very economical, have done more for the accuracy and durability of machines than any other single cause. They have also given us the highly-developed accurate milling cutters which come second only to the



SNOUT BORING MACHINE, HAVING EXTENDED BEARING FOR SPINDLE.



SHOWING OUTBOARD STAY OF MILLING MACHINE, STEADYING BOTH ARBOR AND KNEE.

grinder in the economical production of accurate surfaces.

Another, though subsidiary, element in the production of very accurate machine tools is seen in the specialisation of these tools. Boring can be done more truly as well as cheaply in a machine designed for boring and facing only, than in a common lathe. The same is true of gear cutting, and of many other operations which are done on specialised machines. A familiar example is the modern method of grinding holes with solid emery wheels on a suitable machine, in preference to the old device of using lead laps charged with emery in a lathe. Another is the separation of spur gear cutting, or worm wheel cutting from that of bevel wheels, each being relegated to its own special machine.

Yet another subsidiary difference is seen in improved methods of clamping and holding work. Pulleys are now better tooled on pulley lathes than on lathe face plates. Work which would be sprung on planing machine tables by clamping down, is preferably pinched edgewise. Light pieces which would spring on the surfacing grinder can be held without spring by magnetism, or by the older device of plaster of Paris. Pieces that would be distorted on the tables of milling machines and shapers are gripped better in suitable vices. Slender articles that would spring between lathe centres for want of steadies, or in grinders for want of a spring to the tailstock mandrel, are run truly by the adoption of these devices. Such examples might be multiplied.

INCREASED OUTPUT OF MACHINES.

This is a development which has been in marked evidence in recent years. It is being accomplished in many ways, as in speeding up, using tools of high speed steel, increasing the depth of feeds, increasing the number of tools acting simultaneously, or in rapid succession; and in the latter case by lessening the time intervals between the action of each successive tool. It has also been accomplished by rendering machines semi or wholly automatic, so multiplying the number of machines in relation to the number of hands employed. How much of intricate detail is involved in these developments only those who are very intimately in touch with recent practice know. We will briefly run through these items.

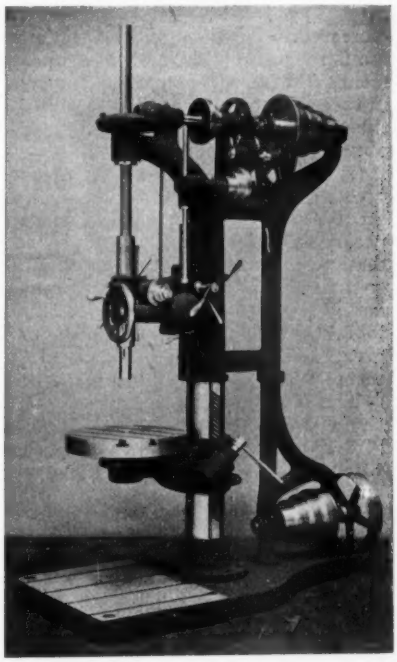
(a) ***Speeding up, and the use of High-speed Steels.***—It is well understood now, though it has not always been fully grasped, that to speed machines beyond their normal limits is not an easy matter. By "normal limits" we understand the rates at which, with given tools and definite rates of speed and feed, material can be removed without injurious results to the work or to the tools used. This supposes that the driving agent, whether belt or gears, is strong enough to perform these normal duties.

But the fact now is that the normal conditions of a very few years ago are not those of the present day. In many instances they were fifty, a hundred, or more per cent. below those which are attained at present. The reason is not

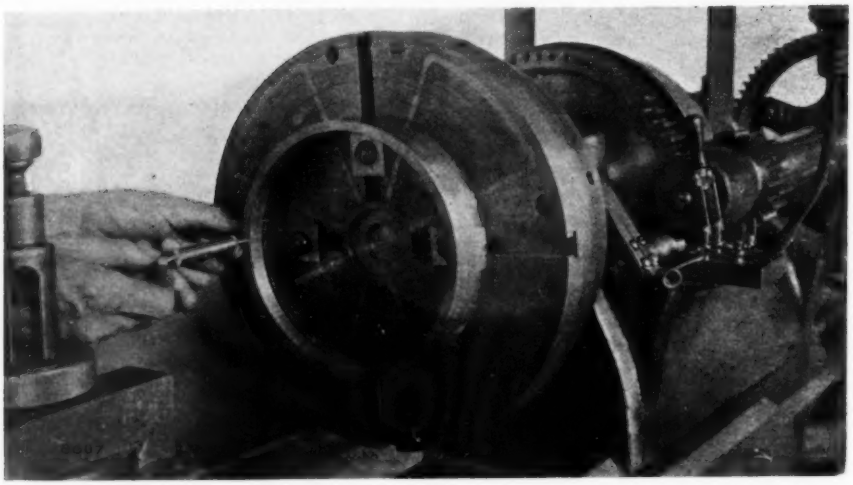
merely that belt or gear power has been increased; but that, concurrently with this, other things that make for efficiency have received attention and been improved. One of these is the stiffening up of frames and spindles already referred to, putting mass into them far beyond that required for purposes of mere strength, so practically eliminating vibration under the heaviest cutting ever demanded.

The minute variations in the shape of tools, on which so much stress was laid by the older writers, have received less attention than improved methods of lubrication, which experience has proved to be of greatly enhanced importance over that of mere tool formation. Yet in some instances the latter receives greater care than ever. Though of less value in the single pointed or edged tools, its importance is greater in the case of drills and milling cutters; and in conjunction with improved lubrication has resulted in a speeding up of drills by at least a hundred per cent., and in permitting of the employment of deeper cuts with the milling tools. With improved lubrication assisting improved tool formation very high speeds and feeds are now secured. Remarkable results have been achieved by the use of high-speed steels which were first shown in operation at the Paris Exhibition in 1900. Concurrently a most rapid development of heavy lathes of practically new design with all-geared heads, capable of withstanding the heavy stresses imposed has taken place, lathes in which broad belts are one of the leading features. The system has now got beyond the lathes, and includes drilling machines, but other developments may be anticipated.

(b) ***Increasing depth of Feeds*** is intimately related to high speeds, standing usually in inverse ratio thereto. It may be considered as an economical alternative to speed, since in a good deal of work preference must be given to slow speeds or traverses and deep feeds, while in others the reverse conditions are more suitable. To give common instances, hard and tough materials are generally treated by the first-named methods, and those which are easily tooled by the second. The deep feeds and slow speeds which are suitable for the steels, generally with back gears in, are not economical in brass and gun metal, for which high speeds and fine feeds by belt power direct, are better. But apart from these general practices, increased economy is not now sought in speeding up alone, but often rather in retaining slow speeds, and taking coarser feeds with abundant lubrication. This is chiefly noticeable in turret lathe practice, and in some gear cutting and milling practice. In all such increase of duty it is essential first that the machine and all its vital parts shall be stiff enough to stand the severe strain, and that the temperature of the work and of the tools shall not be greatly



PILLAR DRILLING MACHINE, WITH SLIDING SPINDLE SUPPORT AND OPEN FRAMING.



MAGNETIC CHUCK HOLDING RING.

increased. These are the practical limits to coarse feeds, and the improvements which are constantly being made in these two conditions have resulted in the economies of coarse cutting now obtained.

(c) ***Increasing the number of Tools acting simultaneously.*** — Here very great development has taken place in nearly all classes of machines. Some of these are also of old date, as the multiple spindle drilling machines, and punches, and in the application of three and four tool heads to planing machines. But great extensions have taken place in recent years.

The older multiple spindle drills are those chiefly employed in boiler and girder work. More recent machines are fitted with spindles which will drill in circles, squares, or other forms, the spindles having wide capacities for adjustment of centres. Such machines are made both in vertical and horizontal forms. One of the most useful applications of the design lies in the drilling of bolt holes in pipe, and cylinder, and pump flanges, in the tyres of railway wheels, in bedplates, standards, and such classes of work, where large numbers of identical pieces have to be drilled all alike. After the centres have been once set, the drilling of eight or a dozen or more holes occupies no more time than the drilling of a single hole.

The application of several tool holders to planing machines may include two on the cross rail, and two on the uprights, with, in a few examples, a fifth on a bracket alongside the bed. These are old designs. But in recent years many milling machines have been built after the planer model in which the spindle heads are arranged similarly to those in the planer, so that four faces are readily operated on simultaneously.

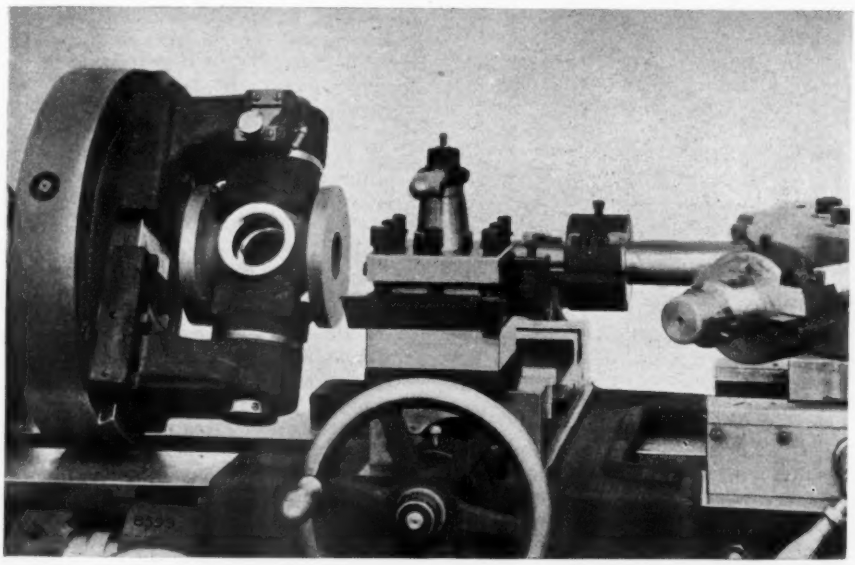
In boring machines and lathes, duplication is practised to a considerable extent. Many boring machines have two heads adjustable for centres. In some cases they are fixed, as for standard work which remains unchanged from year to year. In the lathes the tools are duplicated in twos, fours, sixes, and even eights. In the shafting lathes three tools are generally used.

In the gear cutting machines the practice of duplication has grown. We see it in its widest application in the rack cutting done in some machines,

using milling gear cutters where several cutters are arranged in series, going through several teeth at a single traverse of the table underneath them. It occurs in another form in the use of duplex cutters; in some instances three, or a larger number, are engaged in cutting two or more tooth spaces of a spur wheel. The same result is attained, though in a different way, by cutting through several wheels superimposed at once, or through several racks arranged in line.

In another design, work is expedited in the cutting of bevel wheels in these machines, of which there are several designs now, where two reciprocating tools cut each face of the tooth of a bevel wheel. It is quite probable that machines of this class will in time be able to produce bevel wheels more cheaply even than they can be cut with rotary cutters, in addition to the further great advantage of being perfectly true without any subsequent correction.

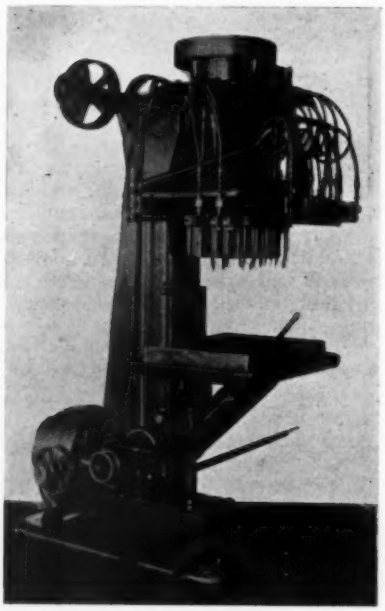
In turret practice, two or more tools are often operating simultaneously on a piece of work, as one turning, and one boring, or one turning or boring, and another screwing. In another way the work of two or three or more separate tools is being done by employing profile or forming tools, as in a good many brass-finishers' lathes, and on the cross slides of turret lathes, a case which is paralleled in many of the profile milling cutters. The economies gained by the use of profile formers are immense in the classes of manufacture to which they are applied. It is not only that the sectional forms are produced at a single application of the tool to the work, instead of by the application of several separate single tools, but that uniformity of any number of pieces is secured. Even these economies are often still further increased by using two profiling spindles on one machine—one roughing the other finishing, or each engaged on dissimilar pieces of work. In some of the hub machines, roughing goes on with one tool, and finishing with



CAPSTAN LATHE CARRYING SETS OF TOOLS ON TURRET AND CROSS SLIDE, AND WITH REVOLVING VALVE CHUCK.

another on the opposite side of the tool slide.

(d) ***Increasing the number of Tools acting in rapid Succession,*** and lessening the time intervals between the action of each successive tool. These are the chief features which characterise modern turret lathe and screw machine design. Though two tools are frequently operating at once in these machines, this is subsidiary to the features named above.



MULTIPLE DRILL, WITH SIXTEEN SPINDLES AND PROVISION FOR SUPPLYING LUBRICANT TO EACH.

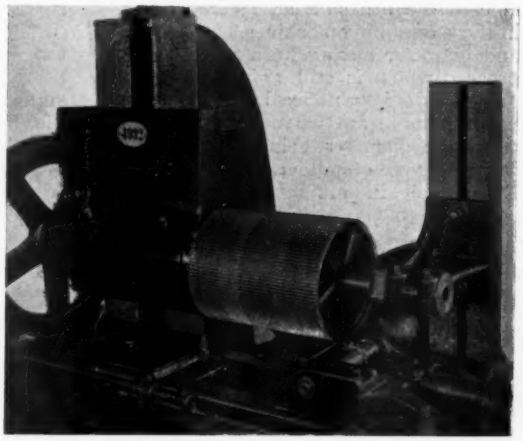
The older design of four, five, or six tools in a turret, all of simple forms, has developed into the composite box tools, some of which comprise several cutting edges, a microcosm of machinery, often of elaborate design, containing provision for movements other than the mere axial movement due to the turret slide. Often now as many as from sixteen to twenty separate cutting operations are performed during one rotation of the turret, including the movements of the cross slide rest, and machine cross slides are frequently fitted in turret boxes. The economy of bringing the tools round rapidly to their work is sufficiently important for many firms to find it worth their while to accelerate the rate of revolution of the turret between each operation. Screw machines and turret lathes have such provision. In some examples ball races are fitted to lessen the friction of turning the turret. And time is further saved in rigging up the tools by giving to each a separate automatic stop. The advantage is that instead of having to make and adjust each tool carefully by a single stop, as in the older practice, the tools are set first, and the stops brought up to suit those several adjustments. This is an important difference from the point of view of economy of time.

In fitting tools to turrets it is not possible to vary the speeds to give the best maximum speed to every tool, and it might seem as though some loss of time must result. But this is avoided by taking the principal or primary operation to set the pace, giving the machine the maximum speed for that, and letting the others come how they will. There is no time lost then, for there would be no advantage even if it were practicable to get one operation finished before the other. That is, say, an external diameter is being turned, and a hole drilled at the same time, with two tools held in one box. Then the machine would be speeded for turning, and the boring would be going on slowly, controlled by the pace set for turning. But the operations would be completed simultaneously.

(e) ***Rendering Machines semi or wholly Automatic.***—Much attention has been paid to this latterly. A few years ago automatic machines were in their infancy, though many turret lathes and screw machines were semi-automatic. In these the operation of the wire-feed involved moving a lever by hand, and so did the partial rotation of the turret from one tool to the next adjacent. At the present time, while the use of machines of this type has vastly extended, many screw

machines, a term by the way which does not indicate their wider utilities, are absolutely automatic, from the moment when the stock bar is inserted and the machine started to the moment when the last piece which the length of bar will supply is completed. The same general remarks apply to the development of gear cutting machines. Originally only semi-automatic, many of these are now fully so, cutting a wheel from start to finish without attendance. These developments have taken place in response to the demands for large numbers of similar articles in which interchangeability is generally an essential condition, combined with cheap production. Such machines would be of little value apart from these requirements, which explains why such provisions are not embodied in general engineers' machine tools.

The design of automatics is not so difficult as it may appear. It follows certain well-defined lines, the principal element in which is the cam, variously applied. The movements are necessarily quite positive, since the slightest variation in distances travelled or traversed would prevent the attainment of uniformity of results in hundreds or thousands of different pieces. And although the pieces produced may be, and often are, of very small dimensions, the machine framings themselves, and the details of slides, cams, shafts, spindles, turrets, feed, and chuck arrangements, are made of exceptional stiffness to be perfectly rigid under the sharp movements of the various operating mechanisms.

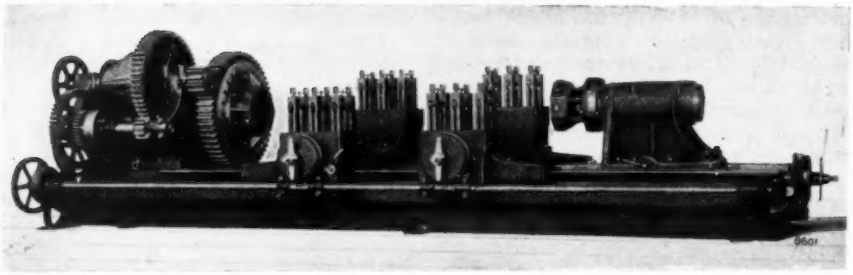


CUTTING TWELVE SPUR GEARS SIMULTANEOUSLY.

DURABILITY, PERMANENCE OF ACCURACY, PROLONGED CAPACITY FOR WEAR.

This may appear to be in direct contradiction to the modern recognised economies of scrapping machine tools before they are worn out. But a distinction may be drawn between the preservation of the accuracy of a tool and its length of service. The point is, that so long as the tool is in use its accuracy must be preserved to ensure the fulfilment of its duties. This is essential in order to enable the tool to fulfil the maximum duty required of it, whether in regard to its capacity for removing metal, or of producing the most accurate results. Hence we find that much greater care is bestowed on recent tools in this respect than in most of their predecessors. Devices for taking up minute quantities of wear are effected with the greatest precision, both in circular bearings and in slides. End thrust is taken on hard or hardened washers, or on ball races. Much more hardening of wearing surfaces is done than formerly. Better materials are insisted on, as phosphor bronze, hard gun metal, compressed white metal, machinery and tool steel, raw hide, &c., with the object of delaying wear.

Another practice having the same object in view is the increasing dimensions given to bearing surfaces. "Extra large" may mean anything, but actual dimensions taken from many recent machines show that manufacturers are



LATHE FOR SLICING INGOTS, &c.

effecting great improvements in this respect. This growth is chiefly noticeable in the necks of lathe spindles and in those of milling machines, both length and diameter having been increased, a process which is still going on. The growth is chiefly noticeable in length, a proportion of from two to two-and-a-half times the diameter being usual. The increasing use of hollow spindles both in lathes and in milling machines has naturally caused an increase in the diameter, but solid spindles have also shared in this increase in dimensions, so that, apart from means provided for taking up wear, the increase of bearing surfaces in contact has resulted in greater durability, to which the hardening and grinding of necks, and the use of hard phosphor bronze, or other similar materials, has contributed.

Drawings of Early Locomotives at South Kensington Museum.

The failure of the movement initiated some years ago to form a national locomotive museum and the lack of accommodation facilities at South Kensington, suggest the obvious alternative of preserving the drawings. It is not, perhaps, generally known that a fine collection of early locomotive drawings exists at Kensington, hence the following particulars may not be without interest to the railway student. It is to be hoped that the extension of the collection will be proceeded with.

THE unique collection of drawings, diagrams, and photographs of old and modern locomotive engines in the South Kensington Museum has from time to time received some important additions, a practice, it is to be hoped, that will be continued. Besides a number of photos, comprising some of a model of Trevithick's engine of 1803, the first locomotive which ever ran upon rails; there are others showing sundry London and North Western engines from the earliest times to those constructed by the late Mr. Webb; several of Taff Vale Railway engines, and of the productions of Messrs. Neilson & Co., of Glasgow, and the Baldwin Locomotive Works, Philadelphia. There are also large blue prints of the North Eastern compound engines of Mr. T. W. Worsdell, and a working drawing of the 4-4-0 type London and South Western Railway engine constructed by Messrs. Dubs & Co., and exhibited at Glasgow in 1901.

In only four cases, unfortunately, are the original engines present to speak for themselves, and this number is little likely to be increased. Space considerations appear to be the chief difficulty, and the efforts of Mr. A. R. Bennett, Mr. Rous Marten, and others, to preserve some of the more important and interesting specimens have so far met with but scanty appreciation. The four engines preserved are Hedley's "Puffing Billy" of 1813, Foster and Rastrich's "Agenoria" of 1829, and the two famous old Rainhill heroes of the same year, "Sansparіel" and "Rocket." The latter, however, has been somewhat altered, but the others are just as they were first built, the four making perhaps the best opportunity for studying the earliest stages of the development of the locomotive that the world affords. Elaborate drawings of each of these, to a scale of $1\frac{1}{2}$ in. to the foot, and ample details of their history may be found adjacent to the engines.

The more comprehensive set of diagrams, however, contains at present six sheets of "wash" drawings, executed with remarkable skill and care by the staff of the Science and Art Department, from original plans and information presented by Mr. C. E. Stretton, of Leicester. Each sheet is framed and glazed, all the drawings being to a scale of $\frac{1}{2}$ in. to 1 ft., and having a table of dimensions, with notes, at the bottom.

The first sheet not devoted to one engine alone contains sections of the "Sansparіel," and "Rocket," and also of their non-existent competitor, Braithwaite and Ericsson's "Novelty." So much, however, has been written about these engines and the Rainhill trials, during the last seventy years, that it is unnecessary to go here into a detailed account of them.

As regards the six principal sheets or charts, they divide themselves naturally into two categories; the engines of certain railways, and those of particular builders. In three or four instances these overlap, the same engine or one of the same class appearing on two sheets, as it was not known when the collection began to be made how far it would be carried. It brings all the noteworthy engines of each railway or builder

together, however, and enables them to be regarded as a group.

STOCKTON AND DARLINGTON RAILWAY.

From the railway point of view, the Stockton and Darlington line naturally comes first.

In the drawings shown, the following ten of the early engines employed are represented, while a table gives particulars of their dimensions:—

No. 1, "Locomotion," was built in 1825 by Messrs. R. Stephenson & Co. This engine is fully described later on; three similar engines, named "Hope," "Black Diamond" and "Diligence," were constructed for this line in 1826.

No. 5, "Stockton," built by Messrs. R. Wilson & Co. of Newcastle in 1826, had four vertical cylinders 6 in. diam. by 18 in. stroke with crossheads sliding in guides and each working, by a return connecting-rod, a driving wheel 48 in. diam. The crank pins on each axle were at right angles, and each cylinder had its own valve gear and blast pipe; the boiler was 13 ft. long by 4·33 ft. diam. and had a single flue. This engine was unsatisfactory and, having been damaged in collision, portions of it were used in building the "Royal George."

No. 6, "Experiment," built by Messrs. R. Stephenson & Co. in 1826, had inclined outside cylinders, 9 in. diam. by 24 in. stroke, acting directly on six coupled wheels 48 in. diam. The boiler, 10 ft. long by 4 ft. diam., contained two through tubes 18 in. diam. each with its own grate; the exhaust was conveyed to the chimney by two blast pipes.

No. 5, re-named "Royal George." This engine was constructed at Shildon Works in 1827 by T. Hackworth, who utilised the boiler, funnel, and wheels of the "Stockton," but provided two new vertical cylinders with valve motions, and an additional pair of driving wheels.

No. 9, "Globe," designed by T. Hackworth and built by Messrs. R. Stephenson & Co. in 1830, had horizontal inside cylinders, 11 in. diam. by 16 in. stroke, placed under the furnace, and four coupled driving wheels 60 in. diam. The boiler was 10 ft. long by 3 ft. diam. and had a single flue with the grate in one end; on the top of the shell was a copper steam vessel in the form of a globe, from which the engine received its name. This locomotive ran till 1839, when its boiler exploded.

No. 13, "Coronation," designed by T. Hackworth and built by Messrs. R. and W. Hawthorn in 1831, was one of thirteen engines built for mineral traffic; it had two vertical cylinders, 14·5 in. diam. by 16 in. stroke, overhanging at the front and driving, through an intermediate shaft, six coupled wheels 48 in. diam., thus having a tractive factor of 70. The boiler was 13 ft. long by 43 in. diam., and had one furnace tube 9 ft. long and 106 small tubes 4 ft. long.

No. 26, "Swift," designed by T. Hackworth and built by Messrs. R. and W. Hawthorn in 1836, had two vertical cylinders 11 in. diam. by 16 in. stroke working, through an intermediate shaft, the driving wheels, which were 48 in. diam. The boiler was 9·6 ft. long and of oval section, 3 ft. wide by 4 ft. high; it contained a fire tube 4·6 ft. long, 29 in. diam., and 102 tubes 5 ft. long; its total heating surface was 256 sq. ft.

No. 27, "Arrow," built by T. Hackworth at Shildon in 1837, had inside cylinders 22 in. diam. by 9 in. stroke which, by rocking levers, drove cranks of 18 in. throw in the driving axle. The pair of driving wheels were 60 in. diam., and there were four other wheels 36 in. diam. The boiler had a rectangular fire-box of copper, and there were 133 tubes.

No. 43, "Sunbeam," designed by T. Hackworth and built by Messrs. R. and W. Hawthorn in 1837, was a four-wheeled engine with single drivers 60 in. diam. and horizontal inside cylinders 12 in. diam. by 18 in. stroke. It remained in use on passenger traffic till 1856.

No. 165, "Keswick," built by Messrs. R. Stephenson & Co. in 1862, was a large passenger engine with a leading bogie and four-coupled wheels 84·5 in. diam.; the cylinders were outside and 16 in. diam. by 24 in. stroke. The boiler had 1,053 sq. ft. of heating surface, 12·75 sq. ft. of grate area, and there was a feed-water heating tank under the footplate.

LIVERPOOL AND MANCHESTER RAILWAY.

Coming now to the Liverpool and Manchester chart figure, there are shown, in chronological order, the "Rocket," the "Northumbrian," the "Planet," the "Mercury," "Samson," and "Liner." All these are four-wheeled engines, the "Northumbrian" being merely a somewhat enlarged "Rocket," with the same outside cylinders driving the leading wheels. The "Planet," of course, is famous for having been the first inside cylinder locomotive, and it had also the peculiarity of the driving axle boxes being on the upper side of the frame. It would have, therefore, to be almost pulled to pieces to get the driving wheels out. The "Mercury" has not this extraordinary defect, although similar in other respects. A small pair of trailing wheels was added later under the footplate, but another engine on the same sheet, "Patentee," 1833, was the first inside cylinder passenger engine ever built with six wheels. The name came from the patent, under which its driving wheels had no flanges. A steam brake was fitted to its driving and trailing wheels, and the engine is of special interest as the prototype of our passenger engines. With the exception of "Liner," which belongs to Bury & Co.'s chart of diagrams, the engines just named, with the little four-wheeled goods, "Samson," were built by R. Stephenson & Co.

It might have been supposed that the Liverpool and Manchester directors would, in consequence of its great success in getting the line started, have dealt almost exclusively with this firm when they wanted engines, and they might have done worse, for in their desire to get hold of new ideas in locomotive construction, they obtained some very bad bargains from builders who had had little or no experience. One of these was the "Swiftsure," the last of the eight Liverpool and Manchester engines here exhibited, and built by Forrester & Co., of Liverpool. It had outside cylinders, 11 in. by 18 in., working cranks keyed on the driving axles, which had outside bearings. Consequently the centre lines of the cylinders were so far apart that, in the total absence of counter-weights, the engine was so unsteady when running as to acquire the *soubriquet* of "Boxer." It was built in 1834, and it is curious that the type, though only used in a very few cases here, is still, with coupled wheels, much used in Austria. The "Swiftsure," although not satisfactory to its owners, is noteworthy, besides representing a new departure, for being the first engine to have four eccentrics. The eccentric rods seem to have stood vertically between the driving wheel and the boiler, two on each side, with a fork or "gab end," the slide valves being driven from them by means of a rocking shaft.

LEICESTER AND SWANNINGTON RAILWAY.

We have now seen the inside cylinder thoroughly established as a mechanical success on the Liverpool and Manchester Railway, and on the next line whose engines are shown in detail at South Kensington it will be found adopted as a standard feature. Its application, nevertheless, was unsatisfactory, and in all the eight engines of the Leicester and Swannington line which are given, the cylinders are fixed beneath a deep smoke-box, the piston-rods working under the leading axle. In this position it was difficult to afford the cylinders adequate support against the stresses set up, but it was many years before the system entirely died out.

The first three Leicester and Swannington engines are four-wheeled goods, in fact all its engines were for goods, or rather coal traffic. These three are practically alike, with outside frames, firebox behind the driving axle, and a wheel-base averaging but 5 ft. "Comet" and "Phœnix" only weighed, full, 9½ tons, which says more as to their extraordinary smallness than columns of details would. "Samson," however, the third of these, was soon made a six-wheeler by adding a small pair of

trailers," thus producing the "coupled-in-front" variety of locomotive. This proved highly successful, the type becoming the favourite one for goods traffic all over the country for many years. It was not, however, the only revolution in locomotive practice due to this little-known Leicestershire colliery line of 1832. So early as February, 1834, R. Stephenson & Co., builders of the above-named three engines, put upon it the "Atlas," the first six-coupled machine ever built with inside cylinders. It was an engine of considerable power, having cylinders 16 in. by 20 in., wheels 4½ ft. in diameter, and weighed 17 tons in working order. The driving wheels had no flanges. Two other engines of the same power and description are shown, viz., the "Vulcan," by Tayleur & Co., 1835, and the "Hector," by the Haigh Foundry Co., Wigan, 1839. "Vulcan" has a large dome next the funnel, but the other two six-coupled have it over the fire-box.

Even that humble piece of railway mechanism, the steam whistle, practically owes its origin to the Leicester and Swannington line, the "Samson" having run into a cart and horse through the inability of the engine-driver to make himself heard with the horn he carried for the purpose. This led to a steam horn or trumpet being substituted. It was screwed into the manhole lid, over the firebox, and soon developed into the whistle, though possibly the first actual steam whistle was used on some other line. The "Ajax," a coupled-in-front engine by the Haigh Foundry Co., 1837, with cylinders 14 in. by 18 in., 4½ ft. driving wheels, 588 sq. ft. of heating surface, and weighing 14 tons full, completes this very interesting set of drawings, with the exception of a Bury engine which will be noticed amongst others by the same well-known maker. Two other engines, "Goliath" and "Hercules," similar to "Ajax," though described on the sheet, are not illustrated thereon, probably because of that similarity.

GREAT WESTERN ENGINES.

Of the railway sheets, next in chronological order is that of the Great Western. The change from the little mineral engines of the old colliery line, with their coupled wheels, to the great single drivers of the broad-gauge, is very striking. A practical man, however, will not be at all impressed with the idea that the latter were, weight for weight, the better engines of the two. There is something disproportionate about the big wheels of the "Vulcan" and "Ajax." The engines are all driving-wheel, and when you look round for the source of the power to drive them, small boilers and fireboxes of the early Liverpool and Manchester dimensions are found. In fact it was soon found that the wonderful speeds these engines were expected to attain could not be got, and would not pay if they could, and in practice the Great Western quickly subsided into a humdrum affair, differing little from its neighbours. Of the two 8 ft. engines just named, "Vulcan" was built by the Vulcan Foundry Co. in 1837, and "Ajax" a year later by Mather, Dixon & Co., of Liverpool. Their cylinders were, respectively, 14 in. by 16 in., and 14 in. by 18 in., and the total heating surface 587 sq. ft. and 377·3. Naturally, they were almost useless, with several others of the same dimensions. "Ajax" had driving wheels without spokes, two discs of boiler plate bolted together forming a substitute for them. These wheels were very noisy, and the experiment was not repeated.

"North Star" was the first Great Western engine, however, and occupies the leading place on the sheet. It was in existence until quite recently, and being designed by the most experienced builders of the time, Robert Stephenson & Co., of Newcastle, proved so successful that it was kept at its daily work till the end of 1870, a period of 33 years. During that time it ran 429,000 miles, but this does not include the very unique experience, for a locomotive, of a voyage to New York and back. It was originally built for an American line, but there being doubts as to the solvency of its purchasers, it was not landed, and returned in the same ship that took it out.

The next engine after the two early 8-footers and a 6 ft. single named "Lion," by Sharp, Roberts & Co., of Manchester, which comes between them, is the "Firefly," 1840. Designed by Sir D. Gooch, this represents the first form of engine designed by the Great Western Co.'s officers, the previous ones having been planned by their builders. "Firefly" was virtually a copy of the "North Star," both having 7 ft. drivers, but the cylinders, 15 in. by 18 in., were made thick enough to be bored out to 16 in. by 20 in., against the 16 in. by 18 in. of the older engine. "Firefly" differed also in having the sides of the firebox brought up to a high, dome-shaped top, with the safety valves at the summit. It answered so well that sixty-two engines, in all, of this class were built, and did excellent service to the end of their days.

In the year 1846, when the "battle of the gauges" was being fought out by the forces of Paddington against all the rest of the railway interest, Mr. Gooch determined to enlarge his "Firefly" class into an 8 ft. engine, with cylinders 18 in. by 24 in., and the same outside frames and high-top firebox. His engine "Great Western" is not shown, but its type, in turn, gave way next year to a similar engine having an additional pair of carrying wheels in front, and minus the dome-shaped firebox. This was the famous "Iron Duke," of which class thirty engines, in all, were built, mostly at Swindon Works, from 1847 to 1855. Eight of these veterans survived until the broad-gauge was finally removed in May, 1892, with fourteen other engines of more recent date, but of practically the same design.

The "Iron Duke" class were much the best-known of all the broad-gauge engines used between London, Bristol, and Exeter, but though hardly up to the traffic requirements of late years, they were for a long time too large for it, and in fact were originally built for no more practical reason than to "show what the broad-gauge could do." The engine had four small wheels in front, with the axle-boxes on each side connected by a single plate spring, which acted also as an equalising lever, an arrangement that was extensively adopted for many years, but was ultimately displaced by the bogie.

The last class of Great Western engine of which an example is given is the 7 ft. coupled eight wheeler "Lalla Rookh." There were but ten of these, all built by Stephenson & Co., in 1855, but they were very fine machines and in their early days no other engines had coupled wheels so large as theirs.

A blue print on the other side of the Machinery Hall represents two very extraordinary Great Western monstrosities, in the shape of engines with their machinery on one carriage and the boiler on another, steam being conveyed from the latter by a jointed pipe. One of these is the "Thunderer," whose 6 ft. wheels were driven by spur wheels geared 3 to 1, making them equal to 18 ft. The other, named "Hurricane," had a single 10 ft. driving wheel, the largest ever made. A controversy arose some years back as to whether the Great Western had more engines than one with 10 ft. wheels, but although some powerful evidence was adduced to show that they had, no definite proof was brought forward, and plenty of evidence shows that at any rate two engines (one of which was the iron-disced "Ajax"), said to be 10-footers, had only 8 ft. driving wheels.

Below the principal sheet of seven broad-gauge engines, is a fine engraving of the Great Western goods engine "Pyracmon," built at Swindon, in 1847, and representing Mr. Gooch's practice for many years. It had 5 ft. wheels, coupled together, cylinders 16 in. × 24 in., and inside frames only, with a wheel-base of 15 ft. 3 in. In working order the weight was but 27¼ tons.

ENGINES BY ROBERT STEPHENSON & CO.

Some ten years ago the first sheet of diagrams of locomotives representing the work of a private firm of makers,

was placed in position. This refers to the Vulcan Foundry Company, of Newton-le-Willows, near Warrington, but in order of date of foundation it is the latest firm of the three. The engines of Robert Stephenson & Co. really came first and their chart contains drawings of ten engines of various dates from 1825 to 1851. The leader is the celebrated old single flue, beam-motion machine, used at the opening of the Stockton and Darlington Railway in 1825 and named "Locomotion." Its cylinders, 10 in. × 24 in. are sunk in the boiler, working transverse cross-beams attached by long tremulous rods to the clumsy, built-up, cast-iron wheels. Very little advance, save the abolition of spur-gearing, is shown upon the "Puffing Billy" of twelve years before. It is satisfactory, however, to think that this venerable antiquity is being carefully preserved by the North-Eastern Railway Company at Bank Top, Darlington. Then came "Experiment" and "America," 1826 and 1828, six-coupled and four-coupled, and notable for being the first engines driven by direct action, without beams or spur-gear or any other complication. Both have the leading pair of wheels, which are 4 ft. in diameter, driven by cylinders planted upon the boiler sides at an angle of about 45 degs., and the single flue with high chimney. The "America" was built for the Delaware and Hudson Canal Company, who desired to use it on a short length of line connected with the canal.

Very similar to it is "Invicta," with its stately funnel. This engine also was only made for to and fro traffic on a short level between two inclines, worked by ropes and stationary engines, on the Canterbury and Whitstable Railway. Although coming next after the "Rocket" in order of construction, it is inferior in design. It had, however, a water-surrounded fire-box and a multitubular boiler, but the wheel-base was only 4 ft. 7 in. against 7 ft. 2 in. in the "Rocket" and it must have been unsteady at even very low speeds. The cylinders, inclined at 33 degs., are 10 in. and 18 in., the wheels 4 ft. and the total length of frame 13 ft. This curious machine, though somewhat altered, is preserved at the Ashford Works of the South-Eastern and Chatham Railway.

Another "Planet" now appears, very like its namesake on the Liverpool and Manchester, but belonging to the Stockton and Darlington, and having its two pairs of wheels coupled. Both have the horn-plates on the top side of the frame, the cylinders working under the leading axle..

The next example of Stephenson & Co.'s early practice is the "Stevens," also a four-wheeled inside cylinder goods engine, and notable as the only locomotive they ever built with a round fire-box. It was made in 1831 for the Camden and Amboy Railroad of America, and was exhibited by the Pennsylvania Railroad Company under steam at the Chicago Exhibition of 1893. Its name, however, was changed to "John Bull" long ago, and other alterations were made, but it is still to be seen in the National Museum at Washington. The "Davy Crockett" follows, which was the first bogie engine turned out at Newcastle. So small was the fire-box that the inside cylinders had room to work at its sides, the cranks being under the footplate. The bogie is well back under the engine, the leading axle being below the centre line of the smoke-box. On the boiler top, as in several other engines of the period, is a fine array of two tall safety-valve covers, a dome and a man-hole lid.

After the "Davy Crockett," which was sent to the Saratoga and Schenectady Railroad early in 1833, comes an example of the six-wheeled, coupled-behind goods engine, a type employed on many English and Continental lines in the thirties. It has inside cylinders, 15 in. by 18 in., outside frames; the driving wheels have no flanges. Next comes the broad-gauge engine, "North Star," the Stephenson sheet concluding with the South Eastern engine, "Folkestone," built in 1851, and shown at the great exhibition of that year. It was constructed on the system of Mr. T. R.

Crampton, which comprised driving wheels behind the fire-box and the suspension of the boiler and its appendages upon three points, viz., a spring on each side in front, each spring serving for two pairs of carrying wheels, and upon the centre of a transverse spring bearing on the driving axle boxes. To enable the arrangement to be combined with inside cylinders, Mr. W. B. Adams' system of a dummy axle with no wheels on it had to be employed, but the plan in general never gave satisfaction, and the few engines of the "Folkestone" class were rebuilt in the ordinary form on every line that tried them. The driving wheels were in this case 6 ft. diam., the cylinders 15 in. by 22 in., and the wheel-base 16 ft.

THE VULCAN FOUNDRY CO.'S ENGINES.

Another particularly interesting collection of departed engines is figured upon the sheet relating to the work of the Vulcan Foundry Co., Newton-le-Willows, near Warrington, which prior to 1847 traded under the name of Charles Tayleur & Co. A small four-wheeled goods named "Titan," with inside cylinders 11 in. by 20 in., built in 1834 for the Liverpool and Manchester Railway, is the first specimen given of their work. Before it left the works, however, a pair of small trailing wheels was added behind the fire-box. It was the firm's eighth engine, and No. 25, placed next, is a curious little four-wheeled "single" for the first railway opened in London, viz., the Greenwich line, 1836. Although the cylinders are inside, the steam-pipes are not, but lead from a large dome close to the funnel. The cylinders were but 10 in. by 16 in., driving wheels 5 ft., the whole machine being very small.

Two early single driver bogie engines for America are given, "Firefly" and "Cincinnati." A good deal alike at first sight, they are found to differ materially on closer inspection. "Firefly" has inside cylinders and is arranged like Stephenson's "Davy Crockett," though the frame is raised in front to give room for the bogie below it. In the "Cincinnati," on the contrary, only inside bearings are used, the sloping cylinders being fixed outside the smoke-box at a considerable height. The driving wheels, 5 ft. in diam., are in front of the fire-box. This machine was built in 1835 for the South Carolina Railroad, of 5 ft. gauge. It has a primitive type of "cow-catcher," like the "Davy Crockett," but "Firefly" has none.

A singular-looking locomotive built for Mr. Hargreaves, who leased the Bolton and Leigh Railway in Lancashire, follows on. It is named "Wellington," and is of the coupled-in-front inside cylinder goods type. The coupled wheels are given as 5 ft. 8 in. diam., though they look more; the cylinders were 13 in. × 18 in. "Franklin" is a very small four-wheeled single, rather like the "Greenwich," engine and was used by a contractor at the formation of the London and Birmingham Railway. "Æolus," another Tayleur, was a brother to "Vulcan" of the Great Western, of which type six were constructed. All these engines, except "Cincinnati," have most elaborately designed wheels, the spokes being carefully turned, something like the legs of a chair or table.

The last three members of the Tayleur-Vulcan family are more modern in date, but sufficiently curious all the same. One is an example, built in 1845, of the once famous "long boiler" pattern, patented indeed by Stephenson's, but sometimes built by other makers. In brief, it consisted of getting all three axles under the boiler barrel, which had to be longer than usual in consequence. Size and arrangement of wheels and cylinders varied. In this case the drivers are the last pair, 6 ft. in diameter. This Bristol and Birmingham engine has outside cylinders 15 in. × 24 in., but some examples had inside cylinders. Whether the middle pair of wheels were the drivers or not, they usually had no flanges, and a high-top square-sided fire-box of the Great Western firm generally went to make up a genuine "long boiler." Though

much used in the forties, the short wheel and great overhang made them unsafe for speeds over about 45 miles an hour, and probably, as a class, they caused more accidents than any other. One rather wonders, in fact, how the obvious defects of this design escaped the notice of the oldest firm of locomotive builders in the world.

The Vulcan Company's No. 316, built for the Shrewsbury and Chester Railway in 1848, reminds one of Stephenson's "Folkestone," in having a wheel-less axle driven by inside cylinders. Instead of only being coupled to one pair of wheels, however, in this case it is connected with both, the engine having but two pairs. Both ends overhang very much. The driving axle is not central, but nearer the trailing wheels; they are 5 ft. 3 in., the base 11½ ft. the cylinders 16 in. × 24 in. One more "Vulcan," finishing the lot, is No. 346, apparently an outside cylinder 5½ ft. single, but on examination it will be seen that only the valve-chests are outside, and driven by eccentrics outside the driving-axle boxes. The cylinders are really inside, 15 in. × 20 in. The machine was built in 1853 for the Shrewsbury and Hereford Railway, and afterwards became the property of the Great Western.

EDWARD BURY'S ENGINES.

Another interesting sheet devoted to private builders illustrates the engines of Edward Bury, of the Clarence Foundry, Liverpool, a firm known latterly as Bury, Curtis, and Kennedy. Commencing trade in 1830, with an engine of extraordinary appearance called "Dreadnought," which had sloping cylinders at the rear end of a return-tube boiler, working a shaft at the funnel end coupled backwards to the three pairs of wheels, Mr. Bury soon evolved his characteristic type of four-wheeled goods. This was mainly distinguished by bar-frames, inside the wheels, with inside cylinders and a round overhung fire-box having a dome-shaped top covered with bright copper. This little engine, built in 1831 for the Petersburg Railroad, in Virginia, had cylinders 9 in. × 18 in., 4½ ft. wheels, and weighed full 10 tons 3 cwts. It was called Class A. Shortly afterwards a similar engine, known as Class B, but with single 5 ft. drivers was made for the Liverpool and Manchester Railway, the two being named "Liverpool" and "Liver" respectively. The Leicester and Swannington engine was a Class A "Bury," and the "Liver" appears on the sheet of Liverpool and Manchester Railway engine diagrams. Though somewhat enlarged in dimensions as time went on, these two types were practically all Bury's stock-in-trade in the way of designs down to 1846. He fitted out the London and Birmingham Railway entirely with A and B engines and there were but few lines that had none of them, but in 1846 circumstances grew too strong for him and it became a question of building six-wheelers or losing trade. Design C then came out; it was really A type enlarged, with a pair of small trailing wheels under the footplate. The result was a coupled-in-front 5 ft. engine of very fair size and power, with cylinders 15 in. × 20 in. Naturally, the next step was to treat the B Class in the same way, producing a 6 ft. "single" engine known as Design D. These two engines were both for the London and North-Western Railway, and built in 1846, the year in which the London and Birmingham and two other lines amalgamated under that famous title.

Having got out of their old groove, Messrs. Bury & Co. went in for wholesale reforms, 1846 also seeing an E Class put upon rails. It might be termed C, still further enlarged, with trailing wheels coupled to the other pairs, in short a six-coupled engine.

The example shown is for the Bristol and Birmingham (now part of the Midland) Railway. Yet further application of the rear-coupling process turned the D Class into F, which was consequently a coupled-behind passenger or mixed-traffic engine. Both these last-named, E and F, had just over 1,000 sq. ft. of heating surface, 16 in. cylinders and 5 ft.

coupled wheels. Their weights are not recorded, but judging from appearances they were light for their size.

It will be noted that in all these engines (with the exception of the "Dreadnought"), the bar-framing, inside cylinders, and semi-circular fire-box with dome top consistently appear, and in many small details their builders were equally conservative. The fire-box tops, indeed, got larger and larger, till, with the double safety valves crowning the edifice, they were virtually as high as the funnel. With increasing pressures of steam, however, the weakness of this shape became obvious, and in 1848 it underwent a sudden and violent suppression. A six-wheeled "single" engine for the London and North-Western came out, similar to the D Class, but with merely a slightly-raised top to the fire-box, although the shape of the box was unaltered in other respects. For distinction's sake the type was called D^1 in the firm's books, but "Bury's low-domed passenger" in the outside world. This low top also appears in the last engine on the sheet, a coupled-behind locomotive for the Great Northern, but in conjunction with an ordinary rectangular fire-box. It was an F^1.

Last but one we have Bury's masterpiece, the great engine "Liverpool," built in 1848 as a reply to the "Iron Duke" Class on the broad-gauge. It had the same sized cylinders, 18 in. × 24 in., and driving wheels, viz. 8 ft., but disposed quite differently. The drivers were behind the fire-box, the cylinders outside, midway along the frame, three pairs of carrying wheels supporting the boiler and front parts. Even more heating surface than Gooch's engines had was packed into a boiler of oval section, but the machine was much too large and heavy for the permanent way of its time and in 1858 was condemned to be broken up. It made a brave show at the Exhibition of 1851, but in no way represented current practice or Bury & Co.'s ideas, being in fact designed by the late Mr. T. R. Crampton, for the London and North-Western. Bury's called it Design H; they began but never finished a G, and gave up business about 1850.

Evidently the object of the maker's sheets has been to include cases like the Canterbury and Whitstable Railway, with its one engine, or small lines like the Bolton and Leigh or London and Greenwich, where perhaps only one or two engines were different from the common practice.

The great merit of the collection of drawings is that being made from the builders' own plans, they represent the engines exactly as they were built. Nearly all the early locomotives were more or less altered after a time, so that pictures of them do not necessarily represent their original condition. Here they can be studied without any misgivings upon that point.

The Transmission of Heat Through a Boiler Plate.

By S. B. BILBROUGH, B.A.

The following experiments, the details of which were presented quite recently to the Transvaal Institute of Mechanical Engineers, were undertaken to verify the hitherto accepted principle that the rate of heat transmission through a boiler plate to water is greater when the water is boiling than when simply being heated to the boiling point. Mr. Bilbrough's results appear to show that such is not the case, confirmation being provided by an independent series of experiments undertaken by Mr. MacLachlan of the University of Leeds and referred to in our last issue. Any gain in efficiency by live steam feed heating can therefore no longer be explained by the principle mentioned.

THE first man to apply live boiler steam to heat the feed water was Mr. John Kirkaldy, and it was to a marine boiler; but his object was not economy, but to cause more equal strains in the boiler plates. Since then it has been very definitely asserted that whenever this type of feed heater was installed, there was a saving in coal consumption. At first this vouched for economy was ridiculed, and naturally so, for did it not seem absurd to condense a portion of the live boiler steam to heat the feed water, when the feed might have been heated direct in the boiler itself? Then came the experiments of Sir William Anderson, 1872, and later of Sir Frederick Bramwell—both of them proving that the rate of heat transmission through a plate to water was very much greater when the water was boiling, than when the water was cold, and simply being heated to the boiling point. If this, then, was the case, the paradox of the economy of live steam feed heating was easily explained; for any boiler would be at its best efficiency when all the water was boiling vigorously all the time, and not cooled at any point by a cold feed. Then later, still going on this principle, which had its origin in the experiments of these two eminent men, it became asserted that the true object of a boiler was to only evaporate water, and not in any way be burdened by heating the cold feed-water. The cold feed could easily be heated in a live steam feed heater, and the only loss possible was a little extra radiation.

In the ENGINEERING REVIEW for January there is a paper by Mr. A. H. Gibson, M.Sc., dealing with this subject, in which he quotes Anderson's figures, and explains the paradox by those experiments. Indeed, there can be no other explanation. This paper is more or less a reply to Mr. Gibson's article—not with a view, however, to deprecating it. On the contrary, it is the very excellence of his arguments and statements that incited me to at least prove the fundamental principles by experiments which would be more analogous to the actual practice of the generation of steam in boilers, than were the experiments of Bramwell and Anderson, from whose results solely has the whole principle originated, and in consequence of which elaborate and difficult theories have been built up. Their experiments were both conducted with steam jacketed pans, and the rate of transmission of heat measured, first, when the water was cold, and second, when boiling away vigorously. Anderson's showed an increase in the B.T.U.'s transmitted when boiling over that of cold water of no less than from 80 per cent. to 133 per cent., Bramwell's an increase of about 164 per cent. Now, the temperature of a steam jacket could not be much over 400° F., unless capable of withstanding over 250 lbs. per

sq. in. pressure. The water in the pan boiled at 212° F., so the degrees difference in temperature would be possibly about 200° F. Does it therefore follow that the same law of rate of heat transmission would hold good if the temperature difference is, say, 2,000° F., as is the case between the fire and the boiler water? It might—but no one can be surprised if the law does not hold good. Yet on this assumption, that the rate of heat absorption through a boiler plate increases enormously if the water is boiling and not cold, the following theories are based:—

That a film of hot water, or water and gas, exists on the inside of boiler plates, causing slow transmission of heat; that this film is only removed by rapid circulation, and consequently a boiling hot feed which would produce continuous and rapid ebullition in the boiler is necessary, and this end is best attained by the use of a live steam feed heater, and herein lies the economy of this apparatus; also that the water-tube boiler, having so much greater rate of circulation than any other type, is bound to be more efficient than a type with slower circulation, because the brisk circulation sweeps the film of hot water, and adhering gases, from the surface of the plates, and, in consequence, absorbs heat from the fire at a much greater rate; and are not these theories clearly borne out by the experiments of Anderson and Bramwell? If you have had a long quiet chat with the representatives of the water-tube type boiler, these principles will be indelibly imprinted on your memory.

It is a good example from history of how many theories can be built one on the other, and conclusions drawn, one being accepted after another, all relying on each other, like a pack of cards supported at one end, and the whole built on a foundation—an experimental foundation, it is true, for no other would be permissible—which has not yet been proved to apply to the superstructure of theories piled on top of it.

It was to ascertain the exact extent of this foundation, or even see if it existed at all, that the following experiments were carried out, *i.e.*, to find more exactly the different rates of heat absorption of a boiler when containing cold water, hotter water, and water boiling vigorously all the time, and the source of heat being, not a steam jacket, but actual flames produced by combustion, and all conditions as nearly as possible analogous to the generation of steam on a commercial scale.

The first thing, then, was to obtain an absolutely constant supply of heat consisting of flames, to apply this to a boiler containing a known weight of water—to measure the rate of rise of temperature per minute up to the boiling point—then to allow the boiler to evaporate a considerable quantity of water, and note accurately the time taken.

By knowing the weight of water in the boiler, the weight of boiler, the weight of scale (if any), and the per cent. of moisture in the scale, and the specific heat of each, and then measuring the rate of rise of temperature, we at once deduce the net rate of heat absorption in B.T.U.'s per minute. This should show a gradual decrease due to the radiation increasing as the boiler becomes hotter—till the boiling point is reached, when the temperature remains steady. This gives us the net rate of heat transmission through the boiler plate when heating cold water to its boiling point.

Then by weighing the amount of water left in the boiler after boiling for about 2½ hours and multiplying by its latent heat, and dividing by the time, we arrive at the rate of heat transmission per minute during the operation of constant and rapid ebullition. If there is any economy in live steam feed heating or in rapid circulation of boiler water, the heat absorbed when boiling vigorously should greatly exceed the heat absorbed by cold or luke-warm water.

THE EXPERIMENTS.

Description of Apparatus.—The boiler and general arrangement of apparatus is shown in Fig. 1. The boiler was a vertical cylinder, with flat bottom and slightly curved top.

The scale formation on sides was $\frac{3}{32}$ in. thick, and of a fairly soft porous nature.

That on the bottom varied from $\frac{1}{32}$ in. to $\frac{1}{16}$ in. thick, and was very hard. This thickness was carefully measured, and $\frac{3}{64}$ in. is the average thickness over the bottom.

The outside of the boiler next the flame was coated with a thin layer of hard baked soot.

The flame from the blow lamp played over the bottom of the boiler only, and the hot gases rising kept close to the vertical sides of boiler, but very little heat would be transmitted through the sides, if any at all. The flame did not extend beyond the bottom of boiler.

The source of Heat.—It was essential for the success of the experiment that the source of heat should be as nearly as possible constant both in temperature and quantity of heat.

No fire can be kept constant, however carefully managed. Electric heating would not be analogous to actual practice, as the nature of flames is very different from the pure radiant heat of incandescent wires or substances made hot by the electric current. Gas jets and burners would be fairly good, but a separate gasometer

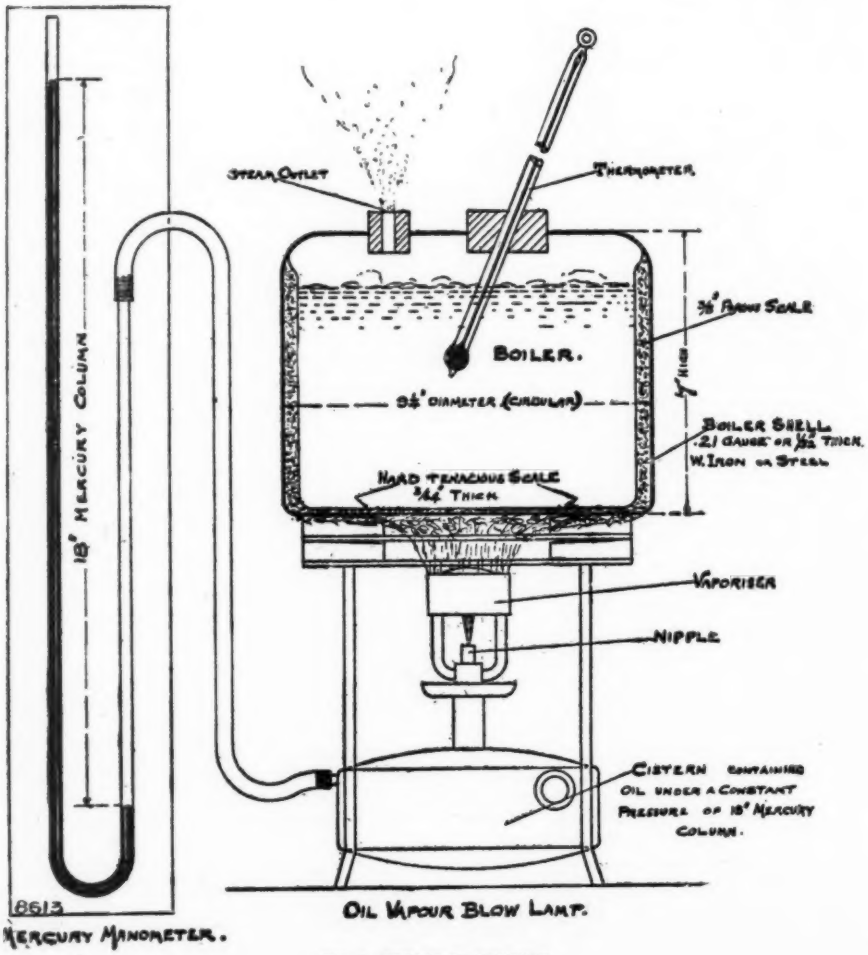


FIG. I.—DETAILS OF APPARATUS.

would be required, and the pressure of gas would need to be kept very constant. Gas taken from the town mains would be out of the question as the pressure is never really constant —the opening and shutting of gas jets in the neighbourhood altering the flow to a considerable extent.

The blow lamp using paraffin oil with a mercury manometer attached to the cistern under pressure, gives as constant a supply of heat as could be wished for. The pressure falls very gradually in the cistern, and is not fluctuating, so by using the pump every few minutes the mercury manometer can be kept steady to within a fraction of an inch.

A continuous source of heat is thus maintained constant in quality and quantity for three or four hours on end.

The character or nature of the flame is important. It was not a pure blue and colourless flame, but contained considerable quantities of yellow, smoky flame, about half yellow and half blue. This was due to the nipple of the vaporiser being slightly enlarged; and, moreover, this mixture of blue and yellow flame would be more comparable to a coal fire, the flames of which are also a mixture of burning C.O. gas, which is blue, and gaseous hydrocarbons. This flame and lamp gave perfect satisfaction throughout the whole of each experiment. Not the slightest difference in the appearance of the flame at any time could be detected. Small circulating eddy currents among the flames remained apparently in the same condition throughout both tests, each of which lasted about three hours.

Nevertheless the precaution was taken of pricking the nipple of the vaporiser every twenty minutes to make certain it was not in any way diminishing the flow of vapour. This precaution was not undertaken because the flame showed any signs whatever of change, but more as a matter of principle. This operation never took longer than two seconds to perform.

The fuel used was white rose oil, and was clean and colourless.

The Thermometer.—The thermometer had a correction of — 2·5° F., but this amount has not been deducted from the readings, as we are only concerned with differences. It was mercury in glass, and graduated in fairly large divisions of 2° each. It was calibrated, but the errors of calibration were less than the errors of observation.

The readings were taken every minute, the time being measured by the second hand of a clock. In plotting the results, however, the rise in °F. is taken over a range of five minutes so as to get a more accurate rate per minute. This is done for every minute as in Tables II. and IV. and Figures 2 and 3.

The barometer was checked against the one at the Government Observatory, Johannesburg, and read 24·44 in. mercury.*

* Boiling point = 204·5° F.

The manometer was kept constant with a head of 18 in. of mercury.

The weighing apparatus was a lever scale with checked weights, reading in lbs. and ozs. The error of weighing would be about $\frac{1}{8}$ oz.

The water used was tap water—not previously distilled or boiled. It would therefore contain dissolved air or gases in quantity equal to any of the make-up water usually supplied to boilers, and would contain considerably more dissolved air than the total feed on a plant using condensers.

TEST I.—WITH SCALE IN BOILER.

Time. p.m.	Temperature °F of the Water in the Boiler.	Difference °F.
5—02	76·0	
		3·5
5—03	79·5	2·0
5—04	81·5	
		4·0
5—05	85·5	5·0
5—06	90·5	4·5
5—07	95·0	4·7
5—08	99·7	4·8
5—09	104·5	6·5
5—10¼	111·0	4·0
5—11	115·0	5·0
5—12	120·0	4·0
5—13	124·0	
		4·5
5—14	128·5	
5—15	134·0	5·5
5—16	138·5	4·5
5—17	143·5	5·0
5—18	148·2	4·7
5—19	152·5	4·3
5—20	157·0	4·5
5—21	161·5	4·5
5—22	166·0	4·5
5—23	170·0	4·0
5—24	174·5	4·5
5—25	178·5	4·0
5—26	183·0	4·5
5—27	187·5	4·5
5—28	191·5	4·0
5—29	196·0	4·5
5—30	200·0	4·0
*5—30¾	204·7	4·7
5—32	204·7	0·0
5—35	204·8	0·1
6—0	204·8	0·0
6—30	204·8	0·0
7—0	204·8	0·0
		0 3
7—15	204·5	0·0
8—0	204·5	

* Boiling commences

Test I.—Air temperature = 72° F. Pressure by manometer = 18″ mercury. Barometer pressure = 24·44″ mercury. Weight of boiler + scale + moisture in scale = 5 lbs. 6¾ ozs. Weight of scale + moisture removed = 2 lbs. 6 ozs. of which 37 per cent. is moisture. Weight of water poured into boiler at start = 10 lbs. 15 ozs. Weight of water poured out of boiler at end of test = 2 lbs. 14½ ozs. Water evaporated = 8 lbs. 0⅞ oz. from and at 212° F. Nett time during evaporation = 149·3 minutes. The weight of boiler + scale + moisture was the same at end of test as at beginning, viz., 5 lbs. 6¾ oz. The flame was steady throughout, to all appearances, and pressure in oil cistern was constant at 18″ mercury.

TEST II.—WITHOUT SCALE IN BOILER.

Time. a.m.	Temperature °F.	Difference °F.
11—30	71·0	
		6·5
11—31	77·5	
		3·0
11—32	80·5	
		6·5
11—33	87·0	
		6·5
11—34	93·5	
		5·5
11—35	99·0	
		6·5
11—36	105·5	
		6·2
11—37	111·7	
		6·0
11—38	117·7	
		5·8
11—39	123·5	
		5·5
11—40	129·0	
11—41	—	—
		11·5
11—42	140·5	
		5·5
11—43	146·0	
		5·0
11—44	151·0	
		4·5
11—45	156·5	
		5·5
11—46	162·0	
		5·2
11—47	167·2	
		5·0
11—48	172·2	
		5·3
11—49	177·5	
		4·8
11—50	182·3	
11—51	187·5	
		4·6
11—52	192·1	
		4·9
11—53	197·0	
		6·8
11—54	203·8	
*11—54½	204·5	0·7
		0·0
11—55	204·5	
		0·5
12—0	205·0	
p.m.		0·0
12—45	205·0	
		0·0
1—15	205·0	
		0·2
1—25	204·8	
		0·0
1—40	204·8	
		0·3
2—0	204·5	
		0·0
2—20	204·5	
		0·0
2—24½	204·5	

* Boiling commences

Test II.—Air temperature = 72° F. Pressure by manometer = 18 in. of mercury. Barometer pressure = 24·44 in. of mercury. Weight of boiler after scaling completely = 3 lbs. ¾ oz. Weight of water poured into boiler at start = 11 lbs. 13¾ oz. Weight of water poured out of boiler at end of test = 3 lbs. 1¼ oz. Water evaporated = 8 lbs. 12½ oz. from and at 202° F. Nett time during evaporation = 150 minutes. The flame was steady throughout, to all appearances, and pressure in oil cistern was constant at 18 in. mercury.

DEDUCTIONS FROM TEST I.

Rise of Temperature in °F. per min.	Mean Temperature of Water °F.	Nett B.T.U.'s absorbed per min. *i.e.* Rise in °F. per min. × 12·49 (the total water equivalent).
3·80	85·5	47·5
4·04	89·6	50·5
4·60	93·0	57·5
4·90	102·8	61·2
5·00	107·5	62·5
4·86	111·9	60·6
4·80	116·5	60·0
4·70	126·8	58·7
4·70	131·8	58·7
4·84	136·1	60·5
4·80	140·5	60·0
4·60	145·5	57·5
4·60	150·0	57·5
4·50	154·8	56·2
4·36	159·1	54·5
4·40	163·5	55·0
4·20	167·8	52·5
4·20	172·3	52·5
4·20	176·8	52·5
4·20	180·8	52·5
4·20	185·3	52·5
4·20	189·3	52·5
4·25	191·5	53·1
4·17	193·8	52·1
4·25	195·8	53·1
4·00	198·0	50·0

Deduced from Curve, Fig. 2, at - 204·5° F.
= 50·4 B.T.U.'s per min.

EVAPORATION OF WATER.

Specific heat of Water = 1·000 (taken constant)
Specific heat of Scale = ·217
Specific Heat of Metal (Iron) = ·115
Average Sp. Heat of Scale + Moisture = ·507
Latent Heat of Steam at 24·44″ Barometer Pressure = 972·8 B.T.U.'s.
Moisture = 37% × 1·0 = 0·370
Scale = 63% × 0·217 = 0·137
0·507

Weight of Scale + Moisture = 2lbs. 6 oz. = 2·375 lbs. × ·507 = 1·204 Water equivalent.
Weight of Boiler = 3 lbs. 0¾ oz. = 3·05 lbs × ·115 = 0·350 " "
Weight of Water in Boiler = 10 lbs. 15 oz. = 10·938 lbs. × 1·0 = 10·938 " "
Total Water Equivalent = 12·492 lbs.

Nett Water evaporated from and at 212° F. = 8 lbs. 0¾ oz. = 8·05 lbs.

Nett B.T.U.'s absorbed per min. during evaporation $= \frac{8·05 \times 972·8}{149·3} = 52·2 \times 98\% =$ 51·2 B.T.U.'s per min.

Steam dryness taken at 98%.

lbs. of water evaporated per hour per sq. foot of flame heating surface = 6·95 lbs.

DEDUCTIONS FROM TEST II.

Rise of Temperature per min. in °F.	Mean Temperature of Water in °F.	Nett B.T.U.'s absorbed per min *i.e.* Rise in °F. per min. × 12·20 (the total water equivalent).
5·60	85·0	68·4
5·60	91·5	68·4
6·24	96·1	76·2
6·14	102·4	74·9
6.00	108·5	73·2
6·00	114·0	73·2
5·76	126·1	70·3
5·66	132·0	69·1
5·50	137·3	67·2
5·40	142·5	65·9
5·34	153·9	65·2
5·24	159·1	63·9
5·30	164·3	64·6
5·16	169·4	63·0
5·10	174·8	62·3
4·98	179·7	61·0
4·96	184·6	61·0
4·87	187·3	59·5
4·90	189·7	60·9
4·75	192·3	59·2
4·90	194·6	60·9

Deduced from Curve, Fig. 3, at - 204·5° F. = 56·7 B.T.U.'s per min.

EVAPORATION OF WATER.

Specific heat of water = 1·000 (taken constant).

Specific heat of metal (iron) = ·115.

Latent heat of steam at 24·44 in. barometer pressure = 972·8 B.T.U.'s.

Weight of boiler = 3 lbs. 0¾ oz. = 3·05 lbs. × ·115 ... ... = 0 350

Weight of water in boiler = 11 lbs. 13¾ oz. = 11·85 lbs. × 1·000 = 11·85

Tota water equivalent = 12·20 lbs.

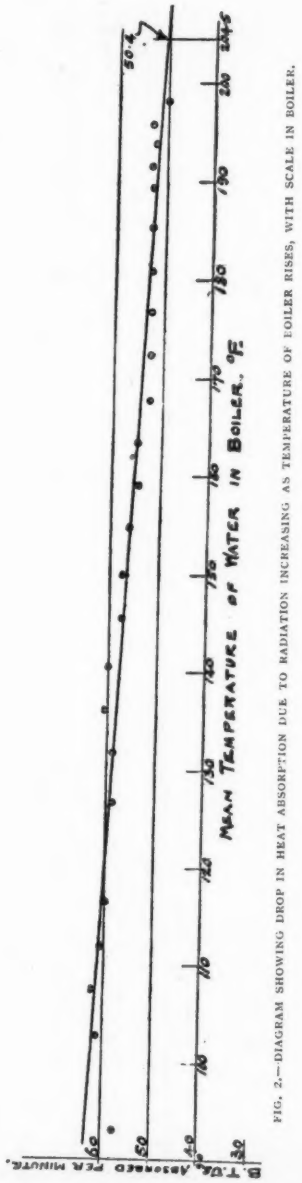


FIG. 2.—DIAGRAM SHOWING DROP IN HEAT ABSORPTION DUE TO RADIATION INCREASING AS TEMPERATURE OF BOILER RISES, WITH SCALE IN BOILER.

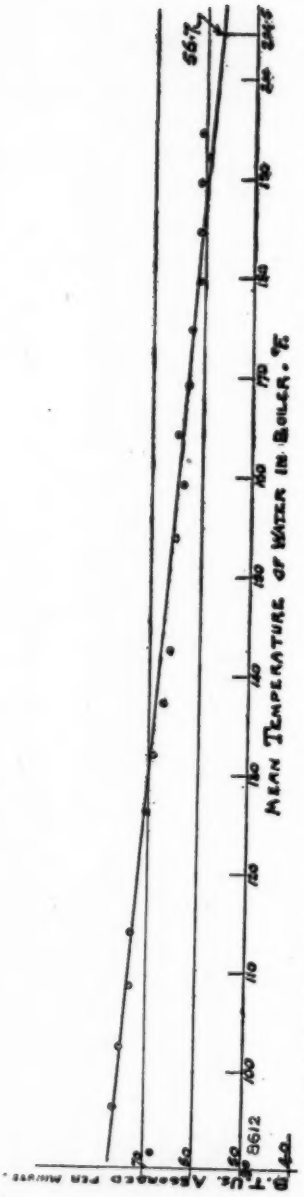


FIG. 3.—DIAGRAM SHOWING DROP IN HEAT ABSORPTION DUE TO RADIATION INCREASING AS TEMPERATURE OF BOILER RISES, WITHOUT SCALE IN BOILER.

Nett water evaporated from and at 202° F. = 8 lbs. 12½ oz. = 8·78 lbs.

Nett B.T.U.'s absorbed per minute during evaporation $= \frac{8{\cdot}78 \times 972{\cdot}8}{150} = 56{\cdot}9 \times 98\ \%$ = 55·8 B.T.U.'s per minute.

Steam dryness taken at 98 per cent.

lbs. of water evaporated per hour per square foot of flame heating surface = 7·54 lbs.

SUMMARY OF EXPERIMENTS.

Comparative results—showing rates of heat transmission, from a constant flame, through a boiler plate, 1st, when heating cold water with only convection currents for circulation; 2nd, when boiling the water, the circulation being vigorous—with scale and without scale formation on the plate.

TEST NO. 1.—*With $\frac{3}{64}$ in. Scale on the Plates.*

	B.T.U.'s
Nett B.T.U.'s absorbed per minute when heating cold water ... =	50·4
Nett B.T.U.'s absorbed per minute when boiling the water ... ... =	51·2
Increase when boiling ... =	0·8
=	+ 1·6%

TEST NO. 2.—*Without any Scale.*

	B.T.U.'s
Nett B.T.U.'s absorbed per minute when heating cold water ... =	56·7
Nett B.T.U.'s absorbed per minute when boiling the water ... ... =	55·8
Decrease when boiling ... =	0·9
=	− 1·6%

	B.T.U.'s
Test No. I.—Total B.T.U.'s transmitted per minute through plate with $\frac{3}{64}$ in. scale ... ... =	61
Test No. II.—Total B.T.U.'s transmitted per minute through plate without scale =	76
Increase without scale ... ... =	15

Efficiency and Capacity Increase on 61 = 25%
Efficiency and Capacity Decrease on 76 = 20%
N.B.—The Scale was very hard and tenacious.

From a study of the figures given in the tables, and with the results plotted graphically in Figs. 2 and 3, it is obvious that there is no increase in the rate of heat transmission through the boiler plate, when the conditions approximate those found in actual practice on a large scale. The very close agreement of both the tests, one having a heavy deposit of scale, and the other with that scale removed, yet neither showing any increase or decrease

of heat transmission when the water is boiling, was a great surprise in view of current theories.

The scepticism of the older engineers on the supposed economy of live steam feed heating, which Mr. Gibson refers to, is, therefore, very well grounded, and could not be more amply justified than by these few experiments.

Experiment I. shows only a difference of 1·6 per cent., an increase, and No. II. exactly the same difference, but a decrease of 1·6 per cent. This very small difference is quite beyond the experimental error or our knowledge of specific heats and latent heat of steam. Without hesitation I would call them exact duplicates.

After the first experiment showing only a difference of 1·6 per cent., it was thought sufficiently conclusive not to need any further proof. But as all the scale had to be removed from the boiler in order to weigh it, the second trial was made to see the effect of the scale as well as to confirm No. I. The confirmation was perfect, and the effect of the scale is not without information.

The only explanation ever yet offered to justify the system of live steam feed heating from an efficiency point of view is that the boiler absorbs more heat when boiling than when heating the colder feed, presumably on account of better circulation, no adhering gas bubbles to the plates, and no hot retarding film of water, and the figures of Anderson and Bramwell are advanced as experimental proofs. These figures, which reveal such a wonderful phenomenon as over 100 per cent. increase of heat transmission under certain conditions, have their true application when applied to the theories of steam jackets, heating coils, and condensers, but cannot be applied to the generation of steam in boilers by fire.

There will be little or next to no loss in employing live steam feed heaters, but there will be no gain.

The apparatus may be useful to deposit scale, and it is possible to work a boiler without feed pumps by that system, but in this paper I am only referring to it as an economiser of heat or fuel, which is its chief claim; and if its chief use is to deposit scale, it had better be called a water softener at once.

I would here emphasise that during boiler tests carried out to prove the extra efficiency of the live steam feed heater, all other causes which might conduce to a gain must be carefully eliminated. A saving in coal over a lengthy period may be due to many causes, not the least of which is the extra attention the boiler-house would receive by the higher authorities in charge, due to a new piece of apparatus being installed.

CONCLUSIONS AND SUMMARY.

1. That the rate of heat transmission through a boiler plate is exactly the same from a fire or flames to cold water as it is to boiling water.

2. That the rate of heat transmission through a boiler plate from a fire or flames is independent:

(*a*) Of the circulation of water in the boiler;

(*b*) Of any layer of gas bubbles adhering to the plates;

(*c*) Of any hot film of water next the plate.

3. That there is no gain in efficiency by live steam feed heating in so far as it is dependent on the above principles, and it is not known to depend on any others.

4. That the effect of a layer of hard tenacious scale $\frac{3}{64}$ in. thick reduces the rate of heat transmission through a boiler plate, and therefore its efficiency and capacity to generate steam, by 20 per cent. in the neighbourhood of the combustion chamber and flames.

(N.B.—This loss may be partially recovered by the remaining heating surface or economisers.)

5. The rate of evaporation in these experiments is about $7\frac{1}{2}$ lbs. of water per sq. ft. of flame heating surface per hour, which is quite a common figure in actual practice.

Workshop Practice

A Method of Planing a Taper to a true Radius.—The object of this article is to describe the construction and operation of an attachment for the planing machine. The application of the apparatus brings a much larger variety of work within the scope of the ordinary machine, and it is hoped that the explanations given may prove lucid enough to enable practical readers to adapt the idea to their own particular cases.

The size and class of work to be done may differ considerably, and, for this reason, all dimensions have been purposely omitted, it being a simple matter to design the different portions to suit given conditions of power, speed and feed.

The machine from which the illustrations were taken is at present dealing with a large segment cast to a radius of about 15 ft., of which Fig. 1 is a line sketch in plan and cross section. The upper surface is to be machined to a taper of half an inch to the foot, but it will readily be understood that there is no limit to the amount of taper that can be tackled, as this is done mechanically by the compound tool box in the ordinary way.

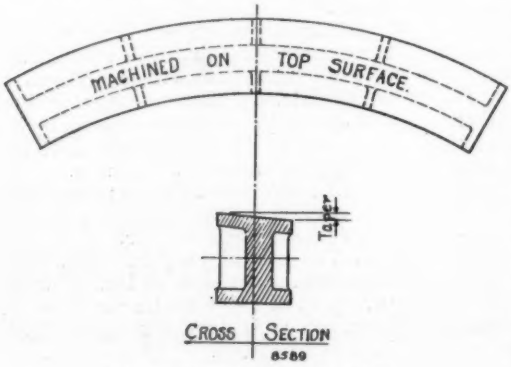


FIG. 1.—METHOD OF PLANING A TAPER.

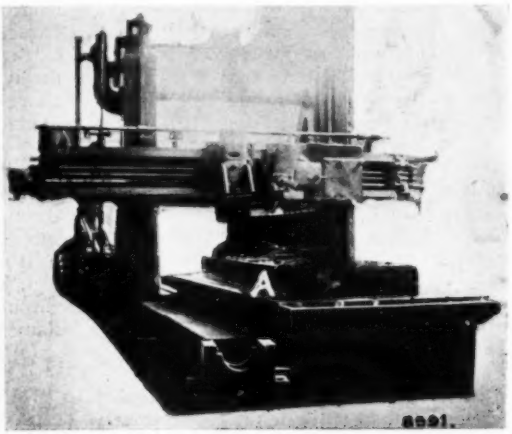


FIG. 2.

The foundation of the attachment consists of a subsidiary table shown at *A*, Fig. 2. It is of hollow section ribbed internally to give rigidity, and it rests, open side downwards, upon and central to the machine table proper. During action the subsidiary table swivels, and its size must be such that the corners do not overlap the machine table when the latter is at the extreme end of its stroke.

The centre pin *B* acts as a fulcrum for the table *A*, and its position is a point upon the cross centre-line of the machine table, but rather to the left in order to allow space for the casting upon the right. A deadeye is bored in a corresponding position through the additional table to receive the centre pin, the scantlings of which pin should be ample to withstand the shearing stresses set up owing to the swivel of the table. It has been found

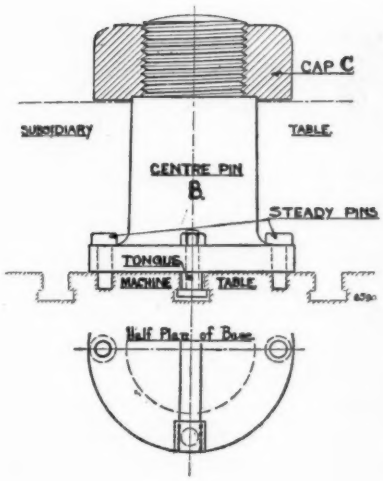


FIG. 3.

advisable to leave a good stiff shoulder on the bottom of this pin as shown.

The design of the centre-pin is shown in Fig. 3. The tongue on the bottom fits into an existing slot in the machine table, and the two square-headed bolts fit under the slot and act as tee-headed bolts. When the centre-pin is in place these bolts are tightened up and clamp the pin to the table. The steady pins serve also as a guide to the correct position of the centre-pin when re-erecting the apparatus at any time. The subsidiary table is placed in position and a cap (*C*, Fig. 3) fitted over the top of pin. The pin, when in place, projects slightly above the top of the subsidiary table. The cap has a recess to suit, the depth of which allows of just sufficient clearance to prevent the table lifting and to ensure its easy action when swivelling.

Near the left hand rear corner of the table *A* is fixed the guide pin *B*, carrying upon its crown the slipper *E*. The design of these is shown in Fig. 4. The pin itself is secured to the table by a nut on the underside, the slipper being a clearance fit upon the upper end, which is reduced to form a collar for this purpose. A brass adjusting strip is fitted to take up any wear consequent upon the sliding action of the slipper along the guide bar *G*, and it is held in place by three set screws *H*. A spring lubricator fitted into the end of the slipper, the oil from which is led to the top of the guide pin, completes the moving part of the apparatus. Attention is now directed to Fig. 5.

This view is taken from the rear of the machine, and shows clearly the guide bar *G*, and the manner of attaching it. The guide bar is rectangular in section, with parallel sides finished to take the slipper *E*, and is placed diagonally across the travel of the bed. It is firmly bolted to a bracket fixed to the left hand tool box (shown at *L*, Fig. 6) and is also secured back and front by the tie rods *J*. The back tie rod is attached to the cross bar *K* (Fig. 5), which is bolted across the side uprights of the machine for this purpose. The front tie is bolted direct to the bottom of the machine cross-slide. The guide bar is also supported by a bolt through the bottom flange of the cross bar *K*.

In order to alter the direction of the guide bar (and consequently the swivel of the table) the ends of the tie rods, the cross bar *K* and the bracket *L*, have slots for the bolts of sufficient width to give the necessary amount of clearance.

The height of the guide bar above the table is designed to give just sufficient headroom for

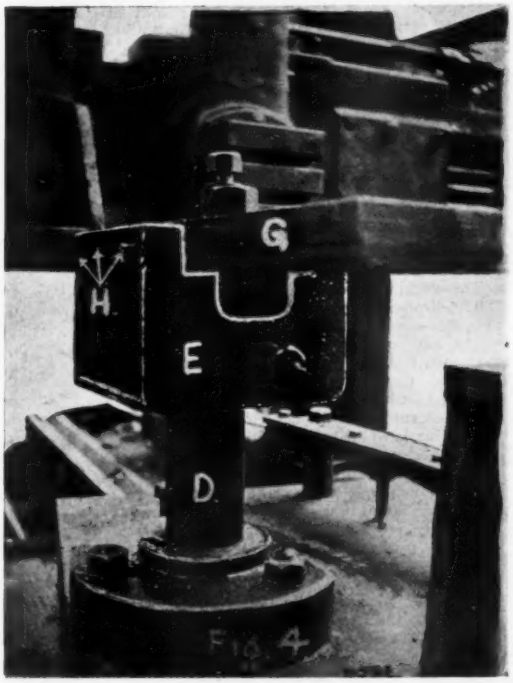


FIG. 4.—METHOD OF PLANING A TAPER.

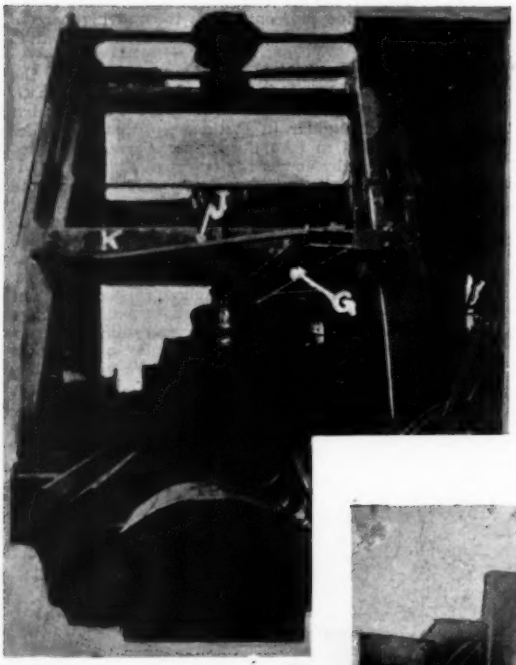


FIG. 5.

the work. The nearer the bar to the table, the less the stress on the guide pin.

The working action is as follows:—

The slipper *E*, during the travel of the machine bed, is guided by the guide bar in a diagonal direction, taking with it the guide pin *D*, which in turn transmits the traversing motion to the table *A*. This table, being fulcrumed by the centre pin *B*, is thus made to swivel, and this turning action, combined with the forward movement of the planer bed, causes the casting to describe an arc of a circle equal in diameter to twice the radius required. By this means the work is always central to the cut and the taper therefore true at every point.

In order to guide the placing in position of the work to be dealt with, a curved plate of approximately the radius of the job, is fitted to the additional table. This saves a considerable amount of time when commencing operations.

The apparatus answers its purpose well and works quite smoothly without causing any appreciable trouble. The chief point to watch is the lubrication. An abundance of oil is necessary upon all parts subject to friction, and especially between the slipper and guide bar. Experience has proved it wise to fit strips of wood in the grooves of the machine table. This precludes the possibility of damage due to a loose tool getting between the two tables.

J. J. C.

Two Interesting Parts to Machine.—We are just finishing an order for machining a large number of brackets and levers the details of which are shown in Figs. 1 and 3. This order has been very interesting not only because we have come out well on the right side with regard to cost, but because the necessary tools and fixtures have been made at quite 50 per cent. below the estimated

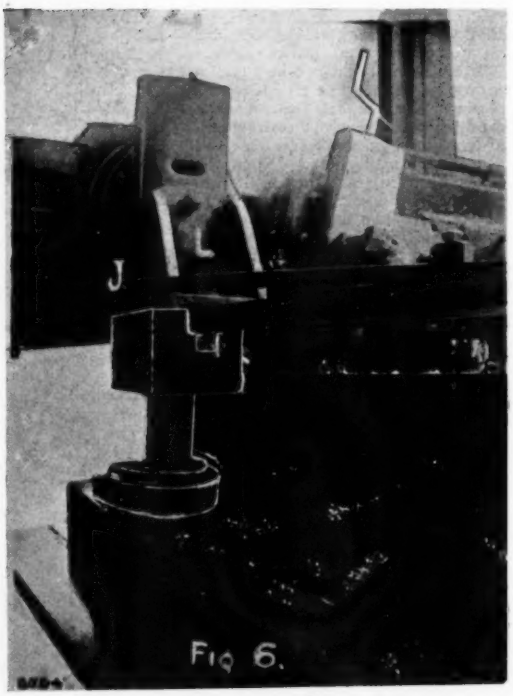


FIG. 6.—METHOD OF PLANING A TAPER

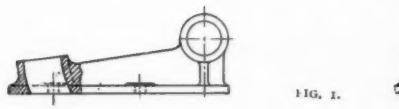


FIG. 1.

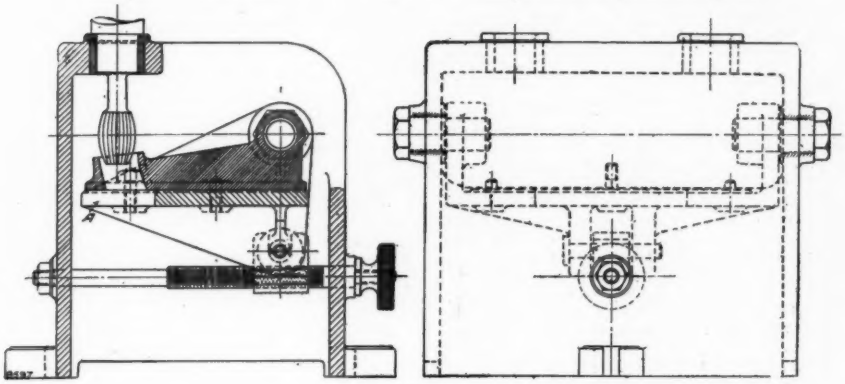
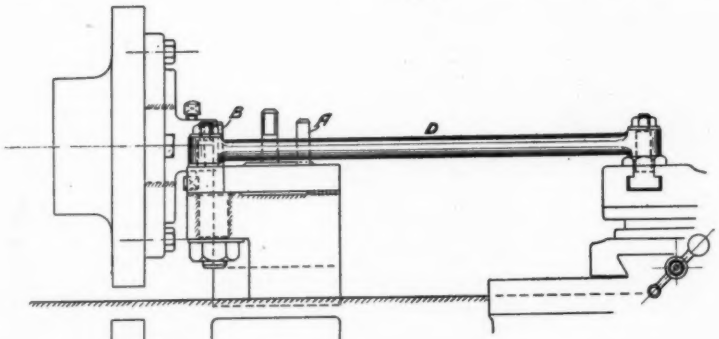


FIG. 2



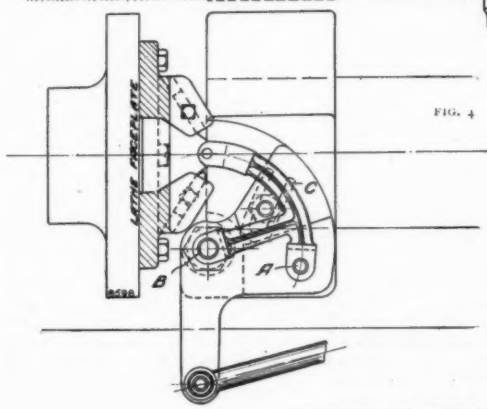


FIG. 4

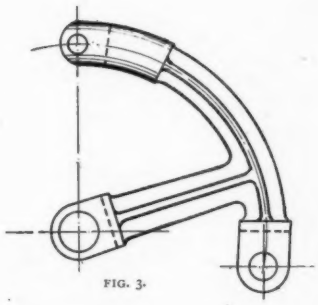


FIG. 3.

TWO INTERESTING PARTS TO MACHINE.

cost. I have not drawn out the drilling jigs and milling fixtures because they are of the usual type, but have sketched out the fixture necessary to machine the radial bearings in the brackets, and a lathe fixture for turning the radial shank on the levers to suit the bearings in the brackets, so that the two parts when together are a good bearing fit.

The machining operations for the brackets which are made of cast iron are as follows:

1. Vertical Miller. Facemill the base.
2. Horizontal Miller. Straddle mill the two hinge-lugs.
3. Driller. Drill and ream the hinge pin holes, drill and face the bolt-holes in a jig.
4. Driller. Using the fixture shown in Fig. 2. Use two dull bushes in the guide holes, and with the platform *A*, set at the correct angle, rough drill for the two radial holes. This operation was not included in the first thirty or forty made, the holes being rough cored; but the sand and scale took the edge off the cutter so we had them cast solid with far better results.
5. Drilling or vertical milling machine using fixture shown in Fig. 2. With a special tool set on the centre-line mill the radial bearing holes feeding the work by means of the screw.
6. File up the casting, removing burrs and sharp edges.

This operation completes the brackets.

The machining operations for the levers which are made from mild-steel drop-forgings are as follow:

1. Driller. Drill and ream two fork pin holes in a jig.
2. Lathe with fixture shown in Fig. 4. Turn the radial end to gauge.

The lever is dropped on to two locating pins *A* and *B* which brings the end to be turned into correct position. The lever is then clamped with the nut and clamp (shown dotted) marked *C*. The table is revolved and the work fed by traversing the lathe saddle, which is connected to the table, by the connecting rod *D*.

3. Horizontal miller. Gang mill the two fork ends, the work being held in special vice jaws.
4. Horizontal miller. Mill the end of the turned shank for a roller path.
5. Driller. Drill and ream hole for roller pin in a jig.
6. Fitter. Trim up the forging removing all burrs, &c.

This operation completes the levers.

I have not described the fixtures more fully because they are so simple.

The estimated and actual costs compared are rather interesting, 2*s.* 4*d.* each was allowed for machining a set of three parts, viz.: one bracket and two levers. The piecework prices actually paid amounted to 10*d.* each for the brackets and 7½*d.* each for the levers.

The estimated cost for the tools was £25. They have actually cost £11 17*s.* There has been about 7 per cent. scrap on the whole order. R. T. S.

PISTON SPEED AND STEAM ENGINE ECONOMY.

At a recent meeting of the North East Coast Institution of Engineers, Prof. Weighton gave some interesting particulars of a series of trials carried out on the experimental engines of the Armstrong College, Newcastle-on-Tyne.

The primary object of the trials was to ascertain by careful experiment the exact effect upon the steam consumption per brake horse power of running engines of ordinary design and proportions, at varying speeds of revolution, ranging from the lowest up to the highest practicable, nothing being altered throughout the series except the resistance against which the engines were working. A second object was to discover, if possible, the maximum permissible speeds of steam and exhaust in such engines, with due regard to economy. This last with a view to the determination of the minimum sectional dimensions of the steam and exhaust ports, openings, and passages, for adoption in proposed engines of this type, without entailing sacrifice of economy in working.

The outstanding results of the trials are summarised as follows:—For every reciprocating steam engine, when change in power is brought about by change in piston speed, there is a certain limit of piston speed at which maximum power is attained, and beyond which the power will fall as the speed is increased. For every reciprocating engine, when change in power is brought about by change in piston speed, there is a certain limit of piston speed with which is associated maximum economy of steam used per horse power developed. For the engines and conditions of the trials, maximum economy in steam used per brake horse power occurred for quadruples at a piston speed of 441 feet per minute, and for triples at a piston speed of 474 feet per minute, the corresponding mechanical efficiencies being for quadruples ·856, and for triples ·87. The maximum economy piston speed depends on several factors, the exact influence of each of which remains to be ascertained, but to a very large extent it is determined by the mechanical efficiency of the engines. An increase in the value of mechanical efficiency will, other things being unaltered, not only raise the economy absolutely, but will advance the maximum economy point on the scale of piston speed. Both maximum power and maximum economy piston speeds are for the brake power considerably lower than for the indicated power, and therefore if the indicated horse power were alone considered, the piston speed of maximum economy would appear to be considerably higher than it is in reality.

Iron, Steel and the Foundry.

Conducted by PERCY LONGMUIR.

STEEL, ITS PROPERTIES AND TREATMENT.

Relative Corrosion of Wrought Iron and Soft Steel Pipes.—In a paper read before the American Society of Heating and Ventilating Engineers, Mr. T. N. Thompson records an investigation as to the relative life of wrought iron and mild steel pipe. At the outset the strong preference for wrought iron is noted; a preference based on the supposed fact that steel pipe is less durable and more given to corrosion. The similarity between wrought iron pipe and soft steel pipe is also noted, and many engineers, contractors, architects, and even steam fitters cannot distinguish a difference. The first part of the investigation represents the examination of pipes corroded in service, and from this the following conclusions are reached:—(1) Both wrought iron and steel pipes which convey steam or hot water will corrode rapidly when buried in wet or damp soil, the corrosion being chiefly external. (2) Both wrought iron and steel pipes which convey hot water become rapidly corroded if the air and other gases naturally solvent in the water are not permitted to escape previous to the passage of the water through the pipes. Such corrosion is chiefly internal. (3) The life of either wrought iron or steel pipes, subject to both the foregoing conditions, is shorter than if the pipes are subject to only one of them. (4) It is not a fact that the destruction of wrought iron pipes is in the form of uniform corrosion, whilst the destruction of steel pipes is in the form of pitting; they appear to be on an average nearly alike, with the difference, if any, in favour of steel. The second part of the investigation lay in direct comparisons of the corrosion of wrought iron and steel pipes under identical conditions. The results are detailed at length, but may most conveniently be summarised in the following table, in which it is assumed that if the corrosion had been continued at the rate which existed during the period of the tests, then the various samples would have corroded through in the number of days specified.

DURABILITY OF THE SAMPLES.

Plain pipe.

No. 10.	Steel pipe	... ...	850·4 days
No. 5.	Wrought iron pipe	... ...	780·5 ,,
No. 6.	Steel pipe	... ...	780·5 ,,
No. 2.	Steel pipe	... ...	759·7 ,,
No. 9.	Wrought iron pipe	... ...	759·7 ,,
No. 1.	Wrought iron pipe	... ...	686·5 ,,

Galvanised pipe.

No. 8.	Steel pipe	... ...	1,162·9 ,,
No. 3.	Wrought iron pipe	... ...	1,162·9 ,,
No. 7.	Wrought iron pipe	... ...	770·0 ,,
No. 4.	Steel pipe	... ...	619·3 ,,

The average life of the plain steel samples is 769·9 days, while the average life of the wrought iron samples is 742·2 days.

The Constituents of Steel.—In a late issue of *Revue de Metallurgie* Professor H. le Chatelier gives a *résumé* of the constitution of steel, noting at the same time that in spite of the numerous researches already done in this field the question is as yet very incompletely known. At the outset it is necessary to distinguish at least four different types of constituents:—(1) Simple or elementary bodies; (2) definite chemical compounds; (3) solid solutions, and (4) aggregates. Simple bodies are represented in steels by graphite or pure carbon and ferrite or iron more or less pure. Of the definite compounds that of cementite Fe_3C is the most familiar. A carbide of manganese of similar formula, Mn_3C, will enter into solid solution with cementite. The cementite of industrial steels nearly always encloses some manganese.

Allotropic Varieties.—It is necessary to recall Osmond's allotropic varieties of iron: α iron stable at ordinary temperatures is characterised by its magnetic properties; γ iron stable at a temperature of 900° is characterised by the absence of magnetic properties and by an electric resistance ten times greater than that of α iron measured

at the ordinary temperature. The transformation from γ to α iron is accompanied by a sharp change in linear dimensions. Finally, a third variety β iron is stable between 750° and 900° C., and is scarcely different from α iron by the absence of magnetic properties.

Solid Solutions.—None of the solid solutions of iron and carbon are stable at ordinary temperatures, a feature which intensifies the difficulty of their study. Of these solid solutions there are at least two, known as austenite and martensite. *Austenite* can only be preserved at ordinary temperatures by a most energetic quenching, and even then only in an incomplete manner. At ordinary temperatures, austenite is always associated with martensite, troosite, cementite, &c. However, in the presence of sufficient nickel or manganese (ferro nickel of 25 per cent. nickel, or manganese steel of 13 per cent. manganese), this solution is stable at ordinary temperatures. Such alloys are not magnetic, and like gamma iron have a high electric resistance. Martensite is a solid solution of carbon in iron distinguished from austenite in that it is very magnetic. It is normal to all steels quenched at or beyond 800° C.

There exists a certain constituent *x*, the nature of which is not yet fixed. This constituent has been variously designated as troosite, osmondite, troosto sorbite, and sometimes even sorbite. According to the researches of Grenet and Charpy, this constituent would appear to be rather a very fine aggregate of ferrite and cementite, judging by the fact that the electric conductivity is similar to that of completely annealed steels which are certainly formed of ferrite and cementite. Finally, in dealing with the obscurity of the language employed, writing of the constitution of steel, Professor le Chatelier refers to the inexact application of certain terms, especially in reference to constituent *x*. Certain authors have incorrectly used the term martensite. In different circumstances the expression "hardenite" is used, but each author applies to the term a particular interpretation. In Professor le Chatelier's opinion there is no need for this term, hence it is preferable to suppress it completely.

The Electrolytic Pickling of Steel.*—According to Mr. C. J. Reed, one of the earliest electro-chemical generalisations was the general law that metals are dissolved at the anode and deposited at the cathode. A no less important law is that under certain conditions of work higher oxides are dissolved at the cathode and deposited at the anode. The particular case to which Mr. Reed draws attention on account of its possible commercial utility is the solution of Fe_3O_4 in sulphuric acid. This oxide is the black scale or fire scale formed when red-hot iron is exposed to air. At low temperatures and dilute solutions this scale is slowly dissolved at the cathode, and if the current density be low the iron below the scale will be dissolved chemically, as in the ordinary process of pickling. If, however, the temperature be maintained at about 60° C., the solution at an acid density of about 1·25, and the current density at about 70 amperes per square foot, the solvent action on the scale becomes very rapid, and the chemical action on the metallic iron is entirely prevented. Under these conditions the removal of the heaviest scale is accomplished in from two to three minutes, and lighter scales in a correspondingly less time. As no iron is dissolved, the method effects a saving in two ways, by a reduction in the quantity of acid used, as compared with that required for the solution of scale alone, and by the saving of all the metallic iron necessarily dissolved in the ordinary process. In the ordinary process the acid dissolves principally the metallic iron, and the scale is largely removed mechanically by hydrogen formed under the scale. In the electric cathode process none of the scale is removed mechanically, as no gas is formed except by the current, and none at all under the scale.

* Transactions American Electro-Chemical Society.

FOUNDRY PRACTICE.

Production of Malleable Castings.—In his second article Dr. Moldeuke* studies the characteristics of malleable iron castings. A malleable casting is stronger than a grey iron casting, but not as strong as a steel casting. It can be bent and twisted considerably before giving way, and approaches cast iron in comprehensive strength; but its most valuable characteristic is resistance to shock. For repeated stresses, under severe service, the malleable casting ranks ahead of steel, and only where a high tensile strength is essential must it be replaced by that material. This is illustrated in the car coupler; a large number of drop tests have shown the high value of the malleable coupler as compared with one of cast steel. This is explained by viewing the constitution of steel castings, as

* The *Foundry*.

in the nature of distinct crystals of pure iron, closely packed together, with other crystals of iron carbide (pearlite ?). The application of a force results in separation along the lines of crystallisation, and cracks extend as in a grey iron casting. Where actual cracks do not occur, a series of strains are introduced, with the result that a little further pressure results in failure. On the other hand, the malleable casting, consisting also of crystals of iron, though impure, has within its structure a network of particles of amorphous carbon. In other words, the malleable casting is a poor steel casting, containing non-crystalline graphite, distributed through and between its crystals. This renders the material weaker on a direct pull, but when it comes to shock the blows will batter the face, but the compression of the cushions of carbon will effectually prevent the transmission of force into the interior.

The fact that the graphite is not crystallised in the malleable casting, as in the case of grey iron, explains why the former is so much stronger. The graphite of a grey iron represents planes of weakness in that the flakes result in a distinct separation of metallic particles, so that when pulled only a small portion of the iron holds together. With malleable there are no such planes of weakness, hence the small spaces occupied by the crystallised carbon do not break continuity and, therefore, do not interfere so much with the holding together of the particles of iron.

Use of Metal Cores.—In the March issue of the *Foundry*, Mr. Geo. Buchanan describes the use of metal cores as distinct from chill cores. In making ready for the mould these cores are warmed and painted with a mixture of boiled linseed oil and plumbago. The cores dry in a few minutes and are then ready for use. Plumbago is mixed with oil to a consistency a little thicker than ordinary blacking, and with this coating chilling appears to be very slight.

The Advantages of Core Moulding.—Some economies offered in the way of pattern and moulding costs by building up moulds from cores, are described by Mr. J. F. Buchanan, in the *Foundry*. Of the methods illustrated are circulating pump chambers and propellers. Of the latter, the writer notes that the truest and safest method is the usual one of building and sweeping in loam. However, for small size solid propellers, say from 4 ft. in diameter downwards, the cored mould offers many advantages. No drawbacks are required, the castings have less fin, and pattern-making is reduced to one-half core box and one blade pattern.

For a three-blade propeller six cores are made from the box, three with the blade pattern in position, and three without. The actual moulding consists in striking up a bed on which to assemble and curb the cores ready for casting. After the cores have been fitted in position, usual methods of binding and casting are employed. Finally, the writer considers that core moulding is not only a method of convenience for intricate castings, it is a method of economy with satisfactory results. Castings by this method are equal to the best finished loam work, and by the use of a core mixture, the moulds are more open and less liable to scab.

Measuring the Capacity of Ladles.*—"A. C. Hemist" gives a method for ascertaining the amount of iron in ladles, by means of a gauge bar. Naturally, the first step is to estimate the capacity of the ladle, and the rule given is:—Multiply the square of the average diameter in inches by the constant 0·196, and multiply this product by the depth in inches. The rule derived from the usual method of finding the weight of circular plates, diameter squared × 0·7854 × 0·2632 = weight in pounds of a plate 1 in. in thickness. This rule has been shortened by the writer, as follows:—0·7854 × 0·2632 = 0·206. This factor reduces the square of the diameter of a circular body of iron 1 in. thick directly to pounds. Hence to find the weight of a circular body of iron 1 in. thick, multiply the square of the diameter by 0·206. This applies in the cold, allowing for the expansion of molten iron, the factor 0·206 becomes 0·196, and the rule previously given follows. The method only applies to total capacities, for the taper in the ladle makes each inch a separate problem, and the only way to obtain capacities at varying depths is to figure each inch separately and add the results. A table of capacities at each depth for ladles, of from 25,000 to 45,000 pounds capacity is given. In connection with these tables, the writer has devised a gauge bar, consisting of a holder attached to the ladle, through which a bar, graduated in inches, is passed, and each gradation is stamped with the capacity of the ladle at the corresponding depth.

*The *Foundry*.

TABLE I.

Burnt Iron: Grey. Burnt Grate Bars. Stove Iron, etc.

No Vanadium added.

No.	Broke at lbs.	Deflection inches.	Modulus of rupture.	Analysis of No. 2.	Per cent.
1	1,500	0·105	29,410	Silicon	2·13
2	1,380	0·100	27,080	Sulphur	0·094
3	1,060	0·070	20,720	Phosphorus	0·638
4	1,020	0·100	19,020	Manganese	0·35
5	1,600	0·085	31,290		
Average	1,310	0·090	25,500		

0·05 per Vanadium added (lump).

No.	Broke at lbs.	Deflection inches.	Modulus of rupture.	Analysis of No. 7.	Per cent.
6	2,430	0·100	47,550	Silicon	2·03
7	2,200	0·100	43,030	Sulphur	0·095
8	2,020	0·100	39,570	Manganese	0·37
Average	2,220	0·100	43,380		

Vanadium in Cast Iron.—In the transactions of the American Foundrymen's Association, Dr. Moldeuke reports a series of experiments with vanadium in cast iron. In all 141 tests are reported, chiefly on two grades of iron, good machinery iron for grey quality, and car wheel scrap, for white iron. High carbon ferro-vanadium was used, chiefly because of its lower melting point, and also because it would be less costly to the founder. Varying additions were made to the ladle, the alloy being previously crushed to powder. The results reached show remarkable gains in properties, thus in one case, with a grey iron, the original test of 2,000 pounds is raised to 2,500, and a white iron of 1,500 pounds is raised to the high value of 3,900 pounds. In order to test the deoxidising effects of vanadium, experiments on burnt material were conducted. These are summarised in the above table.

A NEW METALLIC MIRROR FOR SEARCHLIGHTS.

EVER since the introduction of searchlights for battleships attempts have been made from time to time to substitute metallic mirrors in place of glass ones, which are unsatisfactory due to the fact of their being so readily broken by concussion when firing the guns, and that the silvering at the back of the mirrors is very liable to blister and leave the surface of the glass.

The difficulty of making true parabolic mirrors has been overcome by the Cowper-Coles electrolytic process which briefly consists of depositing by chemical means on the convex side of a glass former or mould a thin silver film, and then spinning the former in an electrolytic cell charged with copper anodes and a copper electrolyte so as to deposit the copper on the silver surface, the process being continued until the silver film has received a sufficient thickness of copper to give the desired rigidity to the parabolic mirror. The glass mould and the electro deposit are then removed from the depositing cell and placed in a vessel containing cold water, the temperature of which is gradually raised until the expansion of the copper is sufficient to cause the metallic mirror to leave the glass former. The silver faced mirror thus produced has as highly polished a surface as the glass and is finally subjected to an after-treatment to prevent the silver from tarnishing and then mounted in a metallic ring (which fits in the projector case) provided with knife edges which firmly grip the edge of the mirror without distorting it. A large number of mirrors made by this process have been supplied to the British Government, some of which were sent out to the South African war.

Mr. Cowper-Coles is now introducing a new metallic mirror which is only partially made by electro-deposition. The mirror has a surface composed of alternate bands or rings of gold and white reflecting surfaces which it is claimed give a more penetrating beam of light both at night and in foggy weather. Objects on which such a beam of light is thrown stand out in greater relief than in a light thrown from a silver white metal mirror and the intensity of the light is so great that it is impossible to aim accurately at the projector.

Another advantage of the new mirrors is that they are not fractured by concussion, and even when penetrated by bullets the area of distortion is very small.

RAILWAY NOTES

Combustion in Locomotive Fire-boxes.*

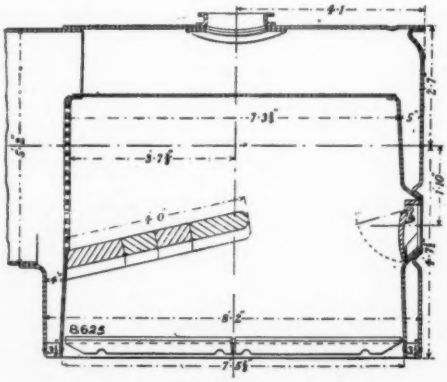
Among the objects of this investigation were those to determine the efficiency of the combustion of the fuel, the loss of carbon due to the production (or loss) of carbon-monoxide and the variations of the products of combustion due to variations made in the demands upon the engine and with the depth of fire.

[When coal, wetted with the water, is employed the re-actions taking place in the fire-box are (1) the drying of the coal and the production of volatile distillation products of the coal which are burnt by the supply of secondary air, or lost as smoke; (2) the combustion of the carbon of the coal by the primary air producing carbon-dioxide and carbon-monoxide; the proportion of each present depends upon the temperature, upon the quantity of oxygen, and upon the velocity of the draught. One gram-molecule of carbon burning to carbon-monoxide yields only 0·29 of the heat evolved when completely burned to carbon dioxide.]

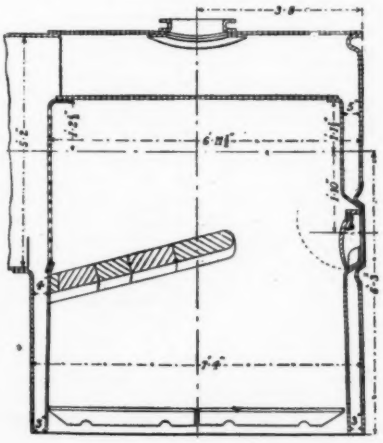
The experiments were made upon London and North-Western Railway locomotives of the "Precursor" and the "Experiment" classes. These two types differ in size and depth of fire-box, the fire-box of the "Experiment" class being considerably larger than that of the "Precursor" class, and only about one-half as deep. The accompanying diagrams show sections of the fire-boxes of these two classes of locomotives.

The first point investigated was the variation of the products of combustion with varying speeds, weight of train drawn and gradients. Samples of the products of combustion were taken during the intervals of firing, each sample being therefore representative of the conditions prevailing in the fire-box during that particular period of working. The results obtained show that the loss due to the formation and escape of carbon-monoxide is greatest at comparatively low speeds, with late cut-off and strong blasts at long intervals as compared with much shorter intervals when running at high speeds; and at speeds of about sixty

* Dr. F. J. Brislee (Proceedings Institution Mechanical Engineers, March 27, 1908. Abst.).



"Experiment" class.



"Precursor" class.

SECTIONS OF FIRE-BOXES USED ON THE LONDON AND NORTH-WESTERN RAILWAY ENGINES.

miles an hour, the quantity of carbon-monoxide in the products of combustion is practically nil. Further, in most cases, there was more than sufficient oxygen present to burn the carbon-monoxide completely, and the escape of this from complete combustion is due, in all probability, to the extremely rapid rate at which the gases are swept through the tubes and cooled down, so that the oxygen and carbon-monoxide had no time to combine. The presence of carbon-monoxide in the products of combustion at low speeds is due to the intermittent character of the air-supply. The escape of the exhaust steam up the funnel takes place in a series of "puffs," and the interval between each "puff" varies with the speed of the train; hence the products of combustion are left in contact with the strongly heated fuel for a time interval depending upon the rapidity with which the "puffs" follow each other, and so partial reduction of the carbon-dioxide to monoxide takes place. Then, at the next "puff," the gases are drawn out of the fire-box, along the fire-tubes and into the smoke-box before the complete combustion of the carbon-monoxide has time to take place. The effect of the gradient is that of reducing the speed of the train, thereby increasing the length of time between each "puff;" hence the time during which the products of combustion remain in contact with the incandescent fuel is also increased. The heavier the train, the greater is this slowing down when ascending a gradient; hence the proportion of carbon-monoxide which escapes combustion is greatest when the engine is working heavily, *e.g.*, drawing a heavy train up a steep gradient.

The effect of the vacuum in the smoke-box was next investigated, and the conclusion is reached that the most efficient combustion takes place when the vacuum is relatively small and the speed high. The higher vacua were never steady, but were obtained in a series of jerks. The conditions necessary for the most effective combustion require that the current of air supplied to the fire should be a steady current, and the amount sufficient to render the velocity of combustion great enough for the production of the necessary steam. The employment of the exhaust steam to induce the air supply is only efficient at high speeds, when the "puffs" follow in extremely rapid succession, so maintaining a steady partial vacuum in the smoke-box, while the air is pushed in through the ash-pan dampers and thence through the fire at a moderately high and fairly constant pressure, due to the passage of the engine through the air. When the thickness of the fire is considerable and the air supply is intermittent, as when the steam-blast is employed, and at low speeds, the tendency for the carbon-dioxide to be reduced to carbon-monoxide is greatly increased; hence *a priori* one would expect a much smaller loss of carbon, due to the formation of carbon-monoxide, in an engine with a thin fire than in one having a deep fire. This point was next investigated, the results showing that the percentage of carbon-monoxide is not so high with the "Experiment" as with the "Precursor" class.

The partial vacuum in the smoke-box was found to be less than in the "Precursor" class, due to the decreased thickness of the fire and also to the increased grate area. The "gas-producer" action of the fire-box, resulting in the partial reduction of the carbon-dioxide to monoxide, is very greatly reduced by reducing the depth of the fire. Considering all the drawbacks of the method of supplying air to the fire-box, viz., by draught induced by the blast, the results obtained show a very great efficiency and compare well with stationary and marine boilers employing either natural or forced draught. Dr. Brislee concludes his paper by recommending the employment of a suitable forced draught by means of which the air supply would be under control and its dependence upon the speed of the engine would be eliminated.

Coal Consumption of "Experiments" and "Precursors."—In the ensuing discussion Mr. C. J. B. Cooke, of Crewe, gave some interesting particulars of the every-day working of the two types of engines on which Dr. Brislee conducted his investigations, viz.: "Experiments" and "Precursors" of the L. & N. W. R. Two of these engines were pitted against each other on four of the heaviest and fastest passenger trains running between London and Crewe. The experiment was commenced in October, 1907, the two engines being No. 276, of the "Precursor" type, and No. 1297, of the "Experiment" type. The leading dimensions were:—

"Precursor" Class, 6 ft. 6 in., Four-coupled Passenger Engine.

Cylinders	19 in. in diam. by 26 in. stroke.
Boiler pressure ...	175 lb. per sq. in.
Heating surface ...	301 tubes, $1\frac{3}{4}$ in. external diameter = 1800·5 sq. ft.
Fire-box surface ...	161·5 ,,
Total ...	1962 sq. ft.
Grate area	22·4 sq. ft.
Depth from centre of brick arch to fire-bars—front	3 ft. $5\frac{3}{8}$ in.
Depth from centre of brick arch to fire-bars—back—under tube-plate	2 ft. 6 in.

"Experiment" Class, 6 ft., Six-coupled Passenger Engine.

Cylinders	... ...	19 in. in diam. by 26 in. stroke.
Boiler pressure	...	185 lb. per sq. in.
Heating surface	...	291 tubes, $1\frac{3}{4}$ in. external diameter = 1857 sq. ft.
Fire-box surface	...	133 ,,
Total	...	1990 sq. ft.
Grate area	... ...	25 sq. ft.
Depth from centre of brick arch to fire-bars—front	... ...	2 ft. 4 in.
Depth from centre of brick arch to fire-bars—back—under tube-plate	... ...	1 ft. $5\frac{3}{4}$ in.

These engines made a daily journey from London to Crewe and back—a total distance of 316 miles. The following particulars were also given :—

Trains.	Average Speed between Stations, with a moderate Allowance for Starting, Stopping, &c.	Approximate Weight of Train, Exclusive of Passengers and Luggage.
	miles per hour.	tons.
Euston, dep. 10.0 a.m.		
Willesden, arr. 10.9 ,,	55	$334\frac{1}{2}$
Willesden, dep. 10.12 ,,		
Rugby, arr. 11.37 ,,	56·3	
Rugby, dep. 11.41 ,,		
Crewe, arr. 1.5 p.m.	58	
Euston, dep. 2.0 p.m.		
Willesden, arr. 2.10 ,,	47·1	$359\frac{1}{2}$
Willesden, dep. 2.13 ,,		
Rugby, arr. 3.40 ,,	55	
Rugby, dep. 3.44 ,,		
Crewe, arr. 5.12 ,,	55·2	
Crewe, dep. 4.7 p.m.		
Bletchley, arr. 6.16 ,,	55·7	$281\frac{1}{2}$
Bletchley, dep. 6.18 ,,		
Euston, arr. 7.10 ,,	57	
Crewe, dep. 7.32 p.m.		
Rugby, arr. 9.0 ,,	55·2	$372\frac{1}{2}$
Rugby, dep. 9.5 ,,		
Willesden, arr. 10.32 ,,	55	
Willesden, dep. 10.35 ,,		
Euston, arr. 10.45 ,,	47·1	

The men selected for the work were four of the most experienced main-line drivers and firemen ; they exchanged engines from time to time, and matters were so arranged that both engines and men had their equal share of the working of each train ; by this means identical conditions of working the two engines for a period of five months were obtained. The "Precursor" engine ran 34,348 miles, and burned 882 tons 5 cwt. of coal—equivalent to an average consumption of 57·53 lb. per mile. The "Experiment" engine ran 34,013 miles, burning 793 tons 8 cwt. of coal, the equivalent average consumption being 52·25 per mile. The last-named engine, as compared with the "Precursor" type, had, therefore, saved, in the five months, about 88 tons of coal—equal to 5 lb. per mile, or about 10 per cent. The result proved that the shallow fire-box and larger grate area produced better results than the deep fire-box with smaller grate area. It should, however, be borne in mind, Mr. Cooke said, that expert firing was an important factor, and results would depend to a considerable extent upon the fireman. With the shallow fire-box the latter must handle the shovel skilfully, and constantly watch the condition of the fire to keep the bars from drawing air. The minimised space under the fire-hole door and beneath the brick arch rendered it imperative to fire frequently, and a little at a time ; whilst with the deeper fire-box, and consequently thicker fire, careful firing was not so necessary ; that possibly was one reason why the consumption of the "Precursor" engine was heavier than that of the "Experiment." But important as the question of economical consumption of fuel might be, a tendency existed to make it subservient to time-keeping, and, in this connection, the speaker considered that the following particulars of the time lost and gained by the two engines during the five months might be of interest :—

It was no light task to haul 350 tons up the 1 in 70 gradient from Euston to Camden, pound away on a rising gradient for the first 30 miles out of London, and make Crewe in

—	2 P.M. Train.				10 A.M. Train.				4.7 P.M. Train.				7.32 P.M. Train.			
	"Precursor."		"Experiment."		"Precursor."		"Experiment."		"Precursor."		"Experiment."		"Precursor."		"Experiment."	
	Loss.	Gain.	Loss.	Gain.	Loss.	Gain.	Loss.	Gain.	Loss.	Gain.	Loss.	Gain.	Loss.	Gain.	Loss.	Gain.
October ...	1	29	...	22	10	32	19	24	...	88	...	52	...	45	...	39
November ...	...	35	4	12	17	30	14	16	9	74	...	35	20	38	1	24
December ...	26	29	40	10	27	25	5	19	1	50	10	55	19	55	43	16
January ...	37	30	11	38	42	35	9	7	...	77	...	27	74	39	7	27
February ...	35	27	23	15	22	14	49	7	...	55	...	67	...	73	...	22
Total ...	99	150	78	97	118	136	96	73	10	334	10	236	113	250	51	128
Average per trip	0·68 gain		0·34 gain		0·22 gain		0·47 loss*		4·33 gain		4·34 gain		1·82 gain		1·54 gain	

* This average was brought about by the heavy storms which prevailed on February 24 and 28.

three hours, with stops at Willesden and Rugby. This was a heavy weight to be dragged up hill and down dale at an average speed of about 57 m.p.h., to achieve which many miles had to be covered at over 60 m.p.h. It took a train of the weight of the 10 a.m. ex Euston, stopping at Willesden, 47 minutes to pass Tring, the summit of the incline, and from Tring to Rugby, therefore the average speed would be 62·9 m.p.h.; that, however, was a fair instance of what the L. & N. W. R. engines were doing every day, and some trains were even faster and heavier than the Scotch expresses which had been the subject of the experiment.

4-6-0 Type Tank Engines, North Eastern Railway.

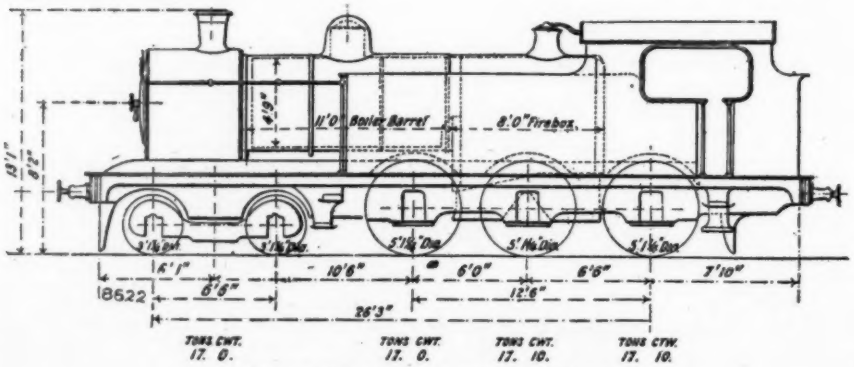
The first batch of a new series of tank engines of the 4-6-0 type has recently been completed at the Gateshead works of the North Eastern Railway Co., to the design of Mr. Wilson Worsdell, chief mechanical engineer. These engines represent a departure in this company's tank engine practice, which has hitherto been limited to the 0-4-4 wheel arrangement. On the Scarborough to Whitby coastline, involving climbs of 1 in 40 for two miles, difficulty has been experienced with the older type engines in dealing with the heavy summer traffic, and as this length of line is not sufficiently strong to permit of an ordinary design of powerful tender locomotive, the present 4-6-0 design was adopted. The leading dimensions are as follows:—

Class W.

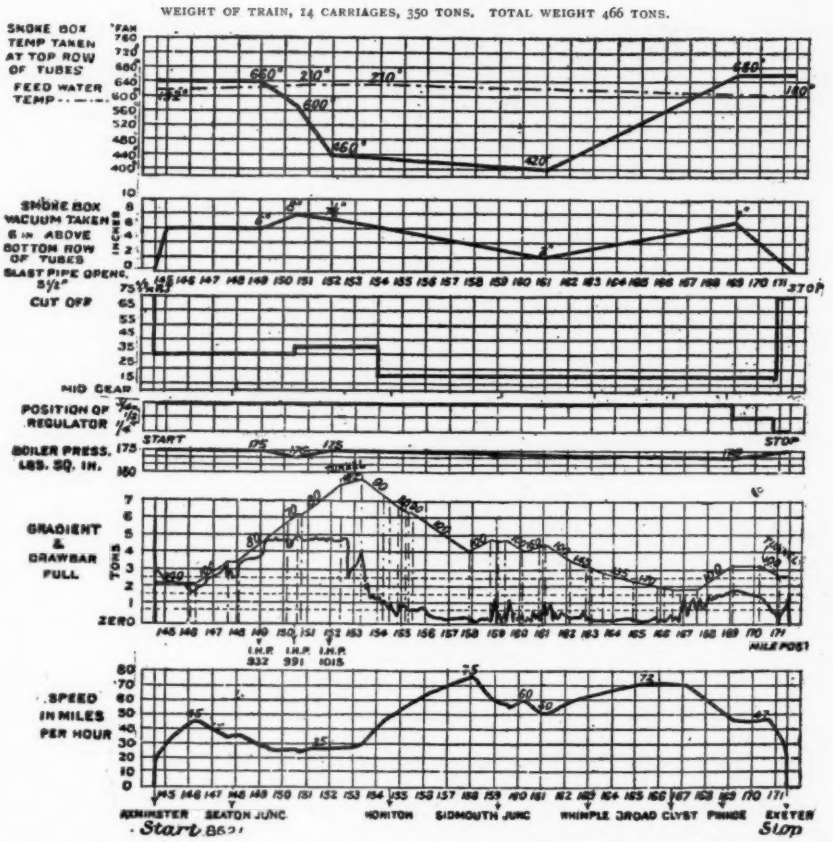
Cylinders, diameter	19 in.
,, stroke	26 in.
Bogie wheels, diameter	3 ft. 1½ in.
Coupled wheels	5 ft. 1½ in.
Bogie wheel-base	6 ft. 6 in.
Coupled	12 ft. 6 in.
Total engine wheel-base	26 ft. 3 in.
Boiler barrel, length	11 ft.
,, ,, diameter	4 ft. 9 in.
,, ,, centre from rail level	8 ft. 2 in.
Tubes, no.	225
,, diameter	1¾ in.
Heating surface, tubes	1,182 sq. ft.
,, ,, fire-box	130 sq. ft.
,, ,, total	1,312 sq. ft.
Working pressure	170 lb.
Firegrate area	23 sq. ft.
Weight on bogie wheels	17 tons.
,, on coupled wheels	52 tons.
,, total	69 tons.
Capacity of tanks	1,500 galls.
Coal capacity	2½ tons.

For the purposes of comparison it may be mentioned that the older tank engines have cylinders 18 in. by 24 in., and 5 ft. driving wheels. The grate area is 15·16 sq. ft., and heating surface 1,097 sq. ft., while the total weight in working order is 51 tons 9 cwt., of which 30 tons 4 cwt. is on the coupled wheels. The design of the 4-6-0 engines is shown in the accompanying outline drawing. It should be mentioned, however, that it has been found expedient to shorten the smoke box of the class, and as no photograph of the engine thus modified is available at the time of writing, its reproduction will be deferred until a later number.

Steam distribution is by piston valves fitted underneath the cylinders, the latter driving on to the crank axle of the leading coupled wheels. The springs of the coupled wheels are fitted with equaliser levers bearing on hardened steel knife edges, and the bogie wheels have the customary inverted springs and equalising beams. A regulating blast pipe and ash ejector is fitted, by means of which the ashes are continuously ejected, thus obviating the accumulation of ashes in the bottom of the smoke box, where there is a danger of



4-6-0 TYPE TANK LOCOMOTIVE, NORTH EASTERN RAILWAY.



CHARTS SHOWING PERFORMANCE OF THE NEW 4-CYLINDER LONDON AND SOUTH WESTERN RAILWAY LOCOMOTIVES.

igniting if a sudden inrush of air occurs. The engines are provided with side tanks and a coal space at the back, and are fitted with the "Westinghouse" and hand brakes. Strengthening operations are now being carried out on the permanent way between Whitby and Scarborough, and pending their completion these locomotives are in operation hauling heavy goods trains in the Leeds district.

Performance of the New 4-Cylinder L. & S. W. Locomotives.

In a recent issue of THE ENGINEERING REVIEW, full particulars and illustrations were given of a new large four-cylinder simple expansion locomotive, designed by Mr. Dugald Drummond, for hauling fast and heavy trains over the severe gradients encountered on the more distant sections of the L. & S. W. Railway. In a recent issue of the *Engineer* are given a number of interesting charts and diagrams, one of which we reproduce, setting out some results obtained on a special journey made with this engine. It is the chart of the run from Honiton to Exeter, up the Honiton Bank, a distance of 26½ miles. It will be seen that a speed of 45 m.p.h. was reached 2½ miles from the Axminster start, dropping to 25 m.p.h. at the Honiton Bank of 1 in 80. This was maintained for about five miles. The draw-bar

pull rose at the same time to 5 tons, dropping subsequently to ¼ ton during the run down the bank when a speed of 75 m.p.h. was reached. The draw-bar pull exhibits the anomaly of remaining practically constant for the next mile, up 1 in 100, which is obviously accounted for by the momentum attained by the train during run down hill. Our contemporary points out that—

> This chart affords an excellent illustration of the part played by acceleration and retardation, *vis viva*, and inertia during the progress of a train, to say nothing about wind, curves, and road resistance. The chart further shows how difficult it is to establish any trustworthy law of train resistance. One thing is very noticeable, namely, the fact that at no time during the run did the draw-bar pull fall to zero. The train never pushed the engine. The regulator was kept full open all the time; but at the highest velocity the engine could do little more than keep out of the way of the train.
>
> Another point of interest is the close relation between the vacuum and the temperature in the smoke-box. They responded to each other promptly and closely. The fact that the smoke-box temperature did not exceed 750° and that for only a single mile, is satisfactory evidence that the boiler is very economical; its economy being no doubt due to the water tubes in the fire-box and the equalising action on the draught of Mr. Drummond's spark arrester. The boiler pressure was 175 lb. = 190 lb. absolute, corresponding to a temperature of 377°, or within 373° of that in the smoke-box; but for many miles the smoke-box temperature did not exceed 500°, or only 123° above that of the steam.

New Type of Trolley.

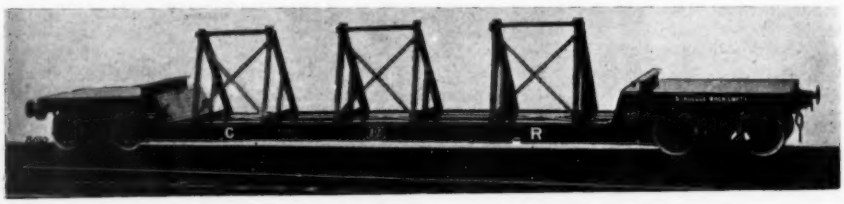
The Caledonian Railway Co. have added to their already extensive stock of special class wagons a new type of trolley, intended particularly for the conveyance of armour plate and miscellaneous iron and steel plates of exceptional dimensions, and up to 30 tons weight.

The trolley measures 61 ft. 8 in. over the buffers, and is carried on two four-wheeled bogies of the diamond frame pattern, the wheels of which have cast steel centres and journals 12 in. by 6 in. diameter.

The well consists of four girders of I section 1 ft. 4 in. deep by 6 in. broad, strengthened by rivetted plates on top and bottom flanges. The centre girders extend close to the inside axles, and are placed at 1 ft. 6 in. centres, in order to afford sufficient side play for the wheels when taking the sharpest curves. The girders are tied together with wrought iron knees of rectangular section 2½ in. by 1½ in., thereby providing a clear space of 35 ft. in length between the centre and side girders, and at a height of only 10 in. above rail level, thus accommodating the utmost size of plates possible with the gauge limitations.

The trestles can be readily shifted from one side to the other to suit loading requirements, and may be removed altogether to accommodate loads of other descriptions, the cross girders of I section over the ends being intended for supporting a long beam when carrying special loads.

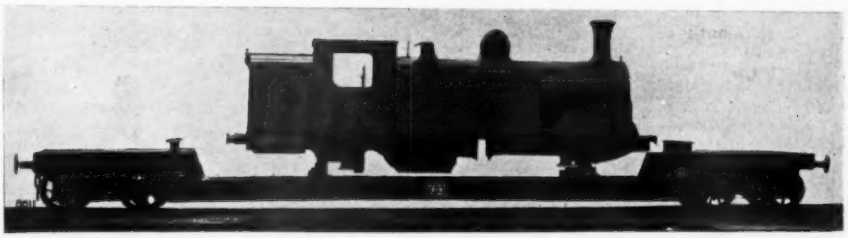
These trolleys (built by the Caledonian Railway Co., to the designs of Mr. J. F. McIntosh, Locomotive, Carriage and Wagon Superintendent), the first of which has just been turned out of St. Rollox Works, combine the following outstanding improvements, viz.: they can carry the largest sizes of plates at present made, *i.e.*, up to 35 ft. by 12 ft. 9 in.; they can traverse curves as sharp as 1⅓ chains radius; and they can convey, by an ordinary goods train at usual speeds, exceptional loads, which otherwise could only be dealt with on Sundays and by blocking the opposite set of rails.



30-TON TROLLEY FOR CONVEYING IRON AND STEEL PLATES, CALEDONIAN RAILWAY.

Enfield to Stevenage Loop Line, Great Northern Railway.

Rapid progress is being made with the new and important loop line which, as will be seen from the map on page 332, forms a continuation of the existing Enfield



THE 30-TON TROLLEY BEING TESTED WITH A LOAD OF SLIGHTLY OVER 30 TONS.

branch line, and it is anticipated that the first five miles to Cuffley will be opened for traffic in the autumn. The new line, the total length of which is 19½ miles, is in part due to the desire of the inhabitants of Hertford town for a direct route to London, and in part to the necessity of duplicating the Great Northern main line beyond Wood Green, from which point to Potters' Bar there are only two roads. To widen this length would have involved some heavy tunnelling and other expensive engineering work, hence it was decided to construct first a line from Enfield to Hertford and to continue it to Stevenage, on the main line, thus providing the doubling accommodation needed at a very much less cost.

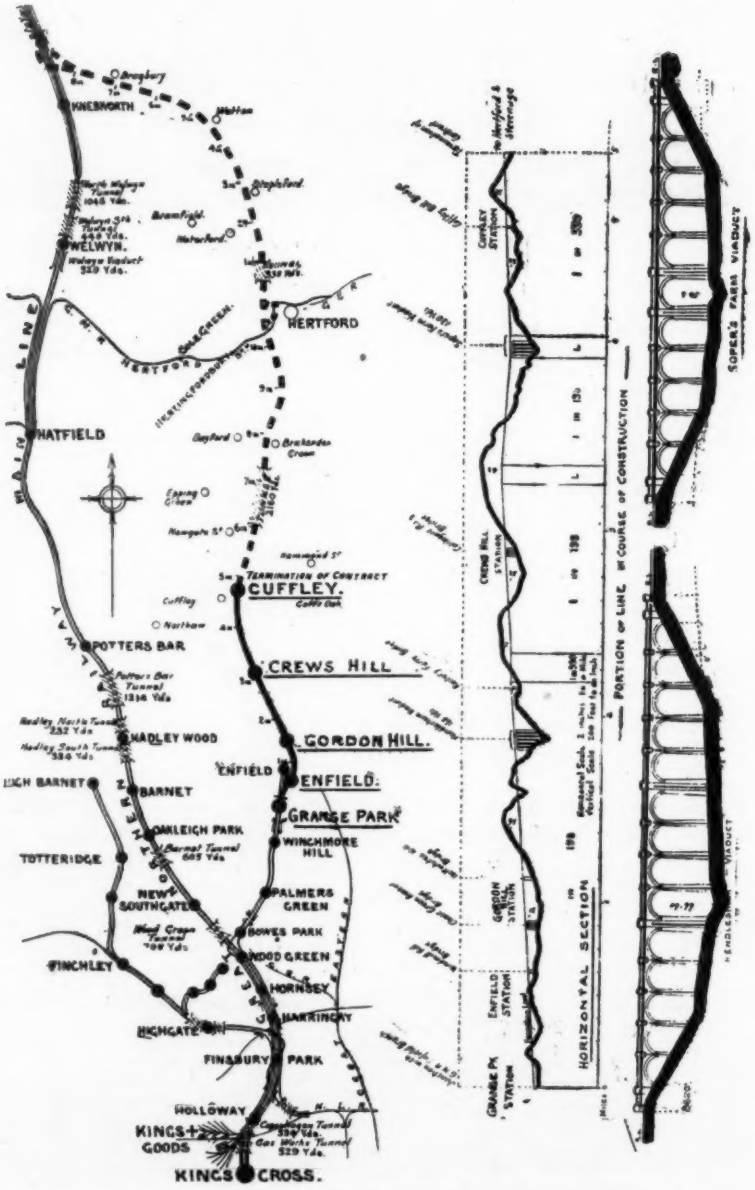
The work on the first five miles beyond Enfield includes three brick arch and four girder under-bridges, and one important five-arch brick over-bridge, carrying Lavender Hill. There are also two extensive viaducts, one at Rendlesham, over a valley 70 ft. deep, which is 165 yards long, built in fourteen segmental arches of 30 ft. span each; and the other at Soper's Farm, 130 yards long, and consisting of eleven segmental arches, also of 30 ft. span. All the abutments and piers of the bridges and viaducts are constructed of concrete encased with red and blue bricks. There are nearly 1,000,000 yards of excavation from cuttings in the London clay, with occasional patches of gravel, one cutting alone containing 450,000 cubic yards of excavation. The maximum depth of the cuttings is 42 ft., and of the banks 43 ft. The slopes of the cuttings and banks have been made 3 to 1, this very flat slope having been adopted owing to the well-known tendency of the London clay to slip. The ruling gradient has been made 1 in 200, which is the same as that on the main line, so that any load which can be hauled on the main line can be diverted to use this alternative route. The line is double throughout, and proper provision is being made for handling goods traffic at the stations. In addition to a new station south of Enfield at Grange Park, there will be a supplementary station at Enfield on the new line, which, it should be noted, commences about half a mile south of the present terminus of the Enfield branch, and the other stations will be at Gordon Hill, Crews Hill, and at Cuffley. The 14½ miles of route between Cuffley and Stevenage offer no particular difficulties, except a big tunnel 2,160 yards long, immediately north of Cuffley. Apart from a short tunnel 338 yards long beyond Hertford, the rest of the route is comparatively easy, and work will be put in hand on this section at an early date. The construction is being carried out under the superintendence of Mr. Alexander Ross, chief engineer to the Great Northern Railway Company, the contractor being Mr. H. M. Nowell.

King Edward VII. Bridge, Newcastle-on-Tyne.*

In this paper the authors describe the construction of the new high-level bridge at Newcastle-upon-Tyne. For nearly 60 years the whole of the North-Eastern Railway traffic between north and south passed over three lines of railway upon the old high-level bridge; and in 1899 the directors of the railway company obtained Parliamentary powers to construct an entirely new bridge with four lines of railway, to accommodate the rapidly-increasing traffic, the new bridge being so located that trains should pass through Newcastle without a change of engines.

The bridge was designed by Mr. Charles

* F. W. Davis and C. R. S. Kirkpatrick, Assoc.MM. Inst.C.E.—Proceedings of the Institution of Civil Engineers.



MAP OF THE NEW ENFIELD TO STEVENAGE LOOP LINE, GREAT NORTHERN RAILWAY.

Harrison, D.Sc., engineer to the northern division of the North-Eastern Railway. The contractors were the Cleveland Bridge and Engineering Company, Ltd., of Darlington.

Foundations.—Electric power was generated at the contractors' yard for working the air-compressors for the caissons, and for driving the whole of the machinery and lighting-plant upon the works. There were three caissons, each 113 ft. long and 35 ft. wide, and sunk to about 70 ft. below h.w.o.s.t. Each caisson was divided into permanent and temporary lengths, the latter being attached to the permanent length at river-bed level. It was carried to a height of about 5 ft. above high-water level. The working-chamber of each caisson was domed, and 9 ft. 6 in. high at the highest point. It was divided into three parts by means of two girders with wide bottom flanges, 3 ft. 6 in. above the cutting edge. These girders were designed to prevent the caissons from sinking too rapidly in soft ground. Holes were made through their webs to enable workmen to have free access to all parts of the working-chamber. There were three shafts to each chamber, which were pear-shaped in plan, and so designed that workmen could descend the ladders without fear of fouling the skips. Each shaft was served by an electric derrick-crane, and the skips were loaded, passed through the air-locks, and tipped into the hoppers without unslinging or re-handling.

The air-locks were designed by Mr. F. W. Davis, with the object of removing the excavated material more quickly than is possible with the ordinary type of lock.

The caissons were built immediately above their final resting-place, and were lowered by means of lowering-chains and hydraulic jacks. As soon as the caisson had been lowered sufficiently to float, concreting was commenced, and continued as rapidly as possible by day and by night until the caisson rested securely on the bed of the river.

Upon several occasions observations were taken of skin-friction, which was found to range from 5 cwt. to 6·65 cwt. per sq. ft. of embedded surface.

The North Approach.—The approach upon the north side is by means of a 10-chain curve. The railway is carried over the existing Forth Banks warehouse by six spans of steelwork; and after passing through the warehouse, Pottery Lane is crossed at a height of 35 ft. above the road. Between Pottery Lane and the north bank of the river are ten semi-circular stone arches of 25 ft. span, terminating in an abutment which forms the north abutment of the main bridge.

The Superstructure, and its Erection.—The bridge consists of two spans of 300 ft. each, with a land span on the north side of 231 ft., and a land span on the south side with an average opening of 195 ft. There are three granite piers in the river, 25 ft. wide, and the clear headway to the underside of the girders is 83 ft. 6 in. from h.w.o.s.t. The piers have curved cut-waters at each end, and are lightened by voids. There are five girders to each span, of lattice design and 27 ft. high, and they are placed 11 ft. apart between centres. The track is carried on longitudinal timbers, resting on floor-plates supported by cross girders attached to the top boom of each main girder. The girders were erected upon timber staging, which was constructed wide enough to build two girders at one time.

The Act of Parliament provided that one of the two waterways should always be kept open during erection. The closing of one channel involved a certain amount of risk to shipping, and in consequence the work was expedited as much as possible. The south river-channel was closed on April 10th, 1905, and reopened upon October 29th, 1905, after the building and removal of staging, and erection of five main girders, weighing 1,636 tons. The north river-channel was closed on October 29th, and reopened on May 26th, 1906.

Experiments were made with sand-blast apparatus for cleaning the steelwork, but the cost was found to work out at 2·16*d.* per sq. ft., or three times the cost of hand labour. There were difficulties in working on a large scale which prevented the system from being used for more than experimental work.

The fan-shaped steel span upon the south side was not contemplated when the work was commenced, but the nature of the foundations upon the south side proved unsatisfactory for arches, and Mr. Harrison therefore decided to alter these to girders. The abutment of this span also forms the wings and abutments for the arches of the south-west and south-east approach curves.

The South Approaches.—During the excavation for the south abutment of the Pipewellgate span, old pit-workings were met with. These were explored, and found to extend under the whole of the foundations upon the south-west and south-east approaches. The workings were therefore cleaned out, and filled up with brickwork in cement. The arches upon the south-east and south-west approach curves were of ashlar in cement, the abutments and span-

drel-walls being of masonry in mortar faced with snecked rubble.

The Cableway.—To expedite construction, a cableway was erected to carry 10 tons, with a clear span of 1,520 ft. The saddles of each tower were 200 ft. above high water, and the dip of the rope was about 65 ft. The towers were of steel framework hinged at the foot, and provision was made at each anchorage for tightening or slackening the main rope. The driving-winch was about 35 yds. west of the tower upon the Gateshead side, and was of 100 h.p. The main rope was 3½ in. diameter, and weighed over 10 tons. Erection was a very difficult matter, owing to the river-traffic, railway-lines, and roadways below, but was successfully accomplished by drawing the main rope over a lighter rope previously secured to the towers. The cableway proved a success in every way, and not only saved considerable expense in carrying out the work, but materially reduced the period of construction. In particular it was proved to be of special advantage for building and taking down the staging for the girders.

All signalling was done by means of flags.

Board of Trade Inspection and Opening.—The bridge was tested by the Board of Trade with a live load of ten locomotives. The maximum deflection in the two river spans was 1/1848th of the span. The formal opening by His Majesty King Edward VII. took place on July 10th, 1906, and passenger traffic was commenced on October 1st, 1906. Mr. A. Cameron, Assoc.M.Inst.C.E., acted as resident engineer for the railway company, whilst the authors supervised the work on behalf of the contractors.

GAS ENGINE RESEARCH.

At a recent meeting of the Institution of Mechanical Engineers, two papers on gas engine problems were presented by Professor Bertram Hopkinson and Mr. James Atkinson. The former dealt with "The Effect of Mixture Strength and Scavenging upon Thermal Efficiency," and the latter with "The Governing and the Regularity of Gas Engines."

Professor Hopkinson said that the success which had attended the use of the new type of optical indicator and the gas-holder method of measuring gas consumption had led him to make tests on thermal efficiency, the points chosen for investigation being the effect of strength of mixture and of scavenging. The engine used was a 40 b.h.p. "Crossley" gas engine. The weakest mixture used in the tests contained about 8·65 per cent. of coal gas when in the engine, the proportion of air to gas drawn in being about 9½ to 1. At the other end of the range the proportion of air to gas was about 7½ to 1, so that the range of mixtures covered all that could be practically used. Within that range the efficiency diminished steadily as the strength of mixture increased, the difference between the weakest and strongest charge amounting to 4½ per cent. in efficiency, or 12 per cent. on the work done. With regard to the causes of higher efficiency with weaker mixtures, much of the superiority was to be ascribed to increase of specific heat, but it was also due to a smaller heat loss in explosion and expansion. Probably about half of the 12 per cent. additional work done per cubic ft. of gas with the weaker mixture was to be credited to each of these causes. With regard to the effect of scavenging, it might be said that the mean pressure realised with the same gas charge should be at least 5 per cent. greater when the engine was scavenging than when it was running fully loaded, and this conclusion was tested by a number of experiments.

Mr. James Atkinson, in presenting his paper, said that for many years hit-and-miss governing was universally employed, and it still remained the usual method for small or moderate size engines. Its economy had practically never been excelled, and it had been the subject of recent improvements in detail. Variable gas admission, caused by opening the gas valve earlier or later during the suction stroke, but always closing it at the end of that stroke, was a method of governing which had come into considerable employment during recent years, and had given satisfactory results in connection with large gas engines. Messrs. Crossleys had recently constructed some tandem engines of 500 to 600 h.p., to which a new type of governor had been applied, in which the operating medium was atmospheric air. Dr. Nicholson, in a report, had stated that the maximum variation in speed from full load to practically no load with this governor was only 1⅜ per cent. of the mean speed with a remarkably low gas consumption. The engine was running on a brake load of 559 h.p., and the gas consumption was 51·94 cubic ft. per b.h.p. per hour. The heat supplied was, therefore, 8,128 b.t.u. per b.h.p. per hour, giving a thermal efficiency on the brake of 31·32 per cent., which he believed to be the highest efficiency that had been obtained in a large gas engine. Quantity governing by the use of cut-off gears was a common method, and an improvement in this respect had been latterly introduced and tested on two four-cylinder engines of about 450 h.p. The maximum speed variation under any change of load did not exceed 1 per cent.

LEADING ARTICLES OF THE MONTH—CURRENT EVENTS—TECHNICAL INFORMATION FROM ALL SOURCES

The Quebec Bridge Disaster—Report of the Royal Commission.

THE collapse on August 29th, 1907, of the great cantilever bridge that was in course of construction across the St. Lawrence at a point eight miles below Quebec, costing the lives of seventy-four persons, was an event which only finds a parallel in the fall of the Tay Bridge in 1879. When constructed the bridge would have the largest span in the world, exceeding that of the Forth Bridge by 90 ft., and much attention was naturally attracted to the structure for this reason.

The cause of the disaster has been elucidated by the investigations of a Royal Commission appointed on the morrow of the disaster, and whose report has recently been issued. Before, however, referring to this and the circumstances connected with the collapse, a brief description of the work may be given.

The bridge was being constructed for the Quebec Bridge Co. by the leading bridge-building firm of America, viz., the Phœnix Bridge Co., of Phœnixville, Pennsylvania, the consulting engineer being Mr. Theodore Cooper, who occupies the leading position as a bridge consultant in the United States.

The bridge, which is of the symmetrical cantilever type, consists of two anchor spans of 500 ft. each and one cantilever river span of 1,800 ft. The latter is composed of two cantilever arms and one central span, and resembles in type and dimensions, though not in detail, the great structure over the Forth. In the latter, however, the cantilever arms are of equal length whereas in the Quebec bridge the shore arm is shorter than the river arm. The top chords of the cantilever—the main tension member—consist of eyebars, while the main compression members or lower chords, constitute a rectangular structure 4½ ft. by 5½ ft. over all, made up of four web plates connected at top and bottom by a light lattice bracing, the latter being replaced by plates at the extremity of the member. In the Forth bridge, the compression members consisted of 12 ft. tubes and were consequently much more rigid. In the Quebec structure, the compression system adopted rendered the determination of the resistance to deformation difficult, if not impossible, to calculate with exactitude. So long as the ribs remained vertical, theoretically such dimensions could be given them to meet the desired compressive strains. This, however, was difficult to achieve in practice, especially in members of large dimensions and highly stressed. If by reason of a slight irregularity in construction, want of precaution during transit or during erection, any of the ribs are deflected or twisted out of line, the subsequent compressive stresses act, not in an axial, but transverse direction and so tend to increase the bend. This is actually what occurred although that circumstance in itself is not sufficient to explain the collapse: as a matter of fact the failure of the lower chord was due to its inadequacy to stand the load actually applied to it.

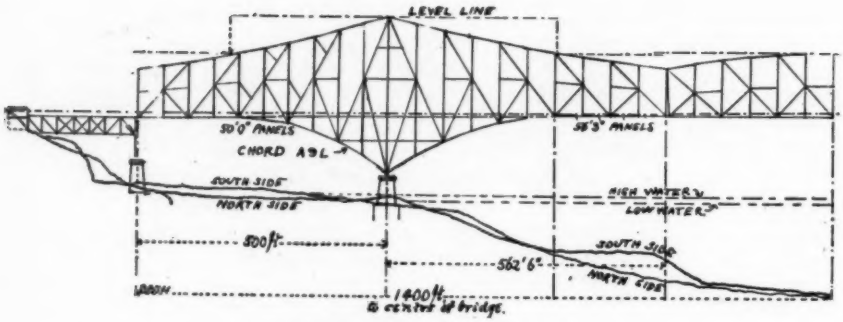
THE REPORT.

The members of the Royal Commission appointed to investigate and report on the catastrophe were Mr. Henry Holgate, of Montreal, civil engineer, Mr. J. G. G. Kerry, of Campbellford, civil engineer; and Prof. John Galbraith, of the University of Toronto. The report, addressed to the Governor General in Council confirms the hypothesis put forward by the profession, viz., that the disaster was due to bad design. The findings and some extracts from the numerous appendices to the report are as follows:—

The Commissioners find:—

(*a*) The collapse of the Quebec bridge resulted from the failure of the lower chords in the anchor arm near the main pier. The failure of these chords was due to their defective design.

(*b*) The stresses that caused the failure were not due to abnormal weather conditions or



HALF ELEVATION OF THE QUEBEC BRIDGE.

accident, but were such as might be expected in the regular course of erection.

(*c*) The design of the chords that failed was made by Mr. P. L. Szlapka, the designing engineer of the Phœnix Bridge Company.

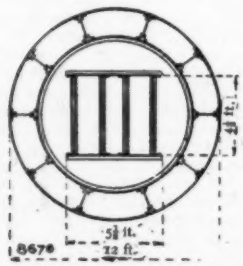
(*d*) This design was examined and officially approved by Mr. Theodore Cooper, consulting engineer of the Quebec Bridge and Railway Company.

(*e*) The failure cannot be attributed directly to any cause other than errors in judgment on the part of these two engineers.

(*f*) These errors of judgment cannot be attributed either to lack of common professional knowledge, to neglect of duty, or to a desire to economise. The ability of the two engineers was tried in one of the most difficult professional problems of the day, and proved to be insufficient for the task.

(*g*) We do not consider that the specifications for the work were satisfactory or sufficient, the unit stresses, in particular, being higher than any established by past practice. The specifications were accepted without protest by all interested.

(*h*) A grave error was made in assuming the dead load for the calculations at too low a value, and not afterwards revising this assumption. This error was of sufficient magnitude to have required the condemnation of the bridge even if the details of the lower chords had been of sufficient strength, because, if the bridge had been completed as designed, the actual stresses would have been considerably greater than those permitted by the specifications. This erroneous assumption was made by Mr. Szlapka and accepted by Mr. Cooper, and tended to hasten the disaster.



COMPRESSION MEMBERS OF THE FORTH AND QUEBEC BRIDGES COMPARED.

(*i*) We do not believe that the fall of the bridge could have been prevented by any action that might have been taken after August 27, 1907. Any effort to brace or take down the structure would have been impracticable owing to the manifest risk of human life involved.

(*j*) The loss of life on August 29, 1907, might have been prevented by the exercise of better judgment on the part of those in responsible charge of the work for the Quebec Bridge and Railway Company and for the Phœnix Bridge Company.

(*k*) The failure on the part of the Quebec Bridge and Railway Company to appoint an experienced bridge engineer to the position of chief engineer was a mistake. This resulted in a loose and inefficient supervision of all parts of the work on the part of the Quebec Bridge and Railway Company.

(*l*) The work done by the Phœnix Bridge Company in making the detail drawings and in planning and carrying out the erection, and by the Phœnix Iron Company in fabricating the material was good, and the steel used was of good quality. The serious defects were fundamental errors in design.

(*m*) No one connected with the general designing fully appreciated the magnitude of the work nor the insufficiency of the data upon which they were depending. The special experimental studies and investigations that were required to confirm the judgment of the designers were not made.

(*n*) The professional knowledge of the present day concerning the action of steel columns under load is not sufficient to enable engineers to economically design such structures as the Quebec Bridge. A bridge of the adopted span

that will unquestionably be safe can be built, but in the present state of professional knowledge a considerably larger amount of metal would have to be used than might be required if our knowledge were more exact.

(o) The professional record of Mr. Cooper was such that his selection for the authoritative position that he occupied was warranted, and the complete confidence that was placed in his judgment by the officials of the Dominion Government, the Quebec Bridge and Railway Company, and the Phœnix Bridge Company was deserved.

Owing to the necessity of having the evidence taken in the United States sworn to before a British Consul, written questions were submitted to each witness examined in the United States, and written answers were returned after an interval of some days.

The Commission is greatly indebted to the following gentlemen, who have most courteously furnished information:—Mr. Charles Macdonald, formerly chief engineer of the Union Bridge Company, contractors for the superstructure of the Memphis cantilever bridge; Mr. H. W. Hodge, of Messrs. Boller & Hodge, engineers of the Monongahela cantilever bridge; Mr. Ralph Modjeski, of Messrs. Noble & Modjeski, engineers of the Thebes cantilever bridge; Messrs. Ingersoll & Seaman, of the Department of Bridges of the city of New York; and Messrs. Reynders & Kunz, of the Pennsylvania Steel Company, respectively engineers and contractors for the superstructure of the Blackwell Island cantilever bridge.

We are also indebted for professional advice and assistance to Professor Mansfield Merriman, Professor W. C. Kernot, Professor H. H. Burr, Professor Edgar Marburg, Professor H. M. MacKay, Professor G. F. Swain, and Messrs. W. R. Webster, T. K. Thompson, and E. W. Stern, consulting engineers.

The technical investigations have been by far the most arduous and difficult part of our inquiry, and it is questionable whether they could have been brought to any conclusion without the assistance that these men of expert training and experience have so freely given.

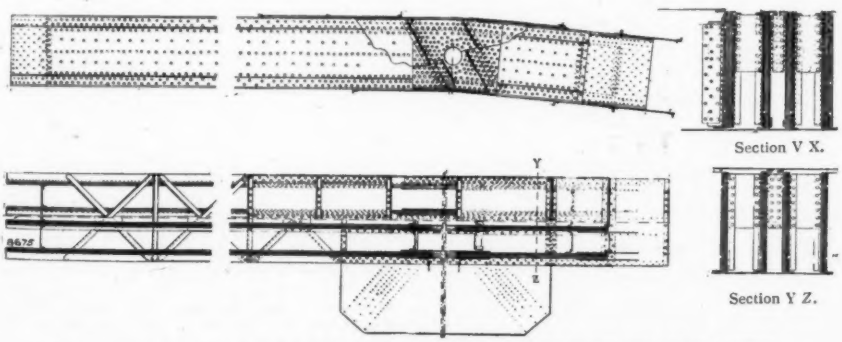
APPENDICES TO THE REPORT.

The Effect of Financial Limitations upon the Design.—The fact that the carrying out of the bridge project was for years delayed by lack of funds being a matter of common knowledge, it was desirable to investigate the effect of this condition upon the design and execution of the work. Mr. Cooper has stated that "during the early progress of the work it was an open secret that the Quebec Bridge Company had but a small amount of money in sight."

In proof of this statement reference may be made to the following facts. Between 1887 and 1898 the Quebec Bridge Company accomplished practically nothing. In 1900 it let the contract for the substructure, payment to be made partly out of subsidies and partly in bonds of the company to be accepted at 60 per cent. of the face value, and offered its superstructure contract on similar terms. In 1900 its securities were thoroughly investigated by the leading firms of American bankers, who declined to invest in them.

The effect of the lack of funds is noticeable in the methods of calling for tenders, and of letting contracts, and in the delays that occurred in the execution of the work.

In September, 1898, the bridge contracting firms were asked to submit tenders upon their own designs, to be drawn in accordance with certain specifications. Practically this meant that each bridge company was asked to spend several thousand dollars on the preparation of plans; and that, in return, it was given an opportunity to bid for a contract to be let by a company of weak financial standing. The result was that, although the magnitude of the work placed it outside the limits of established practice, most of the tenders submitted were made from immature studies based upon insufficient data. The evidence shows that the Phœnix Bridge Company gave more time and attention



DETAILS OF CHORD A9L. THE FAILURE OF WHICH PROBABLY DETERMINED THE FALL OF THE BRIDGE.

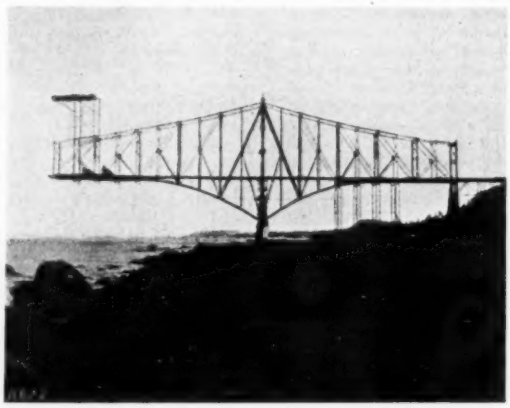
to the competition than any other tenderer, but the error afterwards made by it in assuming the weight of the structure for final designs shows how faulty the estimate accompanying its original tender was. We consider that the procedure adopted in calling for tenders was not satisfactory in view of the magnitude of the work, and was not calculated to produce the most efficient results.

In a memorandum accompanying his original report Mr. Cooper indicated his desire to alter the specifications and to reconsider the length of the main span as soon as proper foundation surveys could be made.

These changes were subsequently made, but it does not appear that economy was the ruling factor in his selections.

In his evidence Mr. Cooper has outlined his intentions in making his alterations, and a desire not to involve the Quebec Bridge Company in a greater expenditure than was at first anticipated is given among them; but it is also stated that he would not recommend any plans that did not promise to give a safe and satisfactory structure.

The facts discussed in this appendix show that, while there is no evidence of any cheap and insufficient work being purposely done by either Mr. Cooper or the Phœnix Bridge Company, there is evidence to prove that the financial weakness of the Quebec Bridge Company seriously interfered with the carrying out of the undertaking.



VIEW OF THE BRIDGE TAKEN SHORTLY BEFORE ITS FALL.

(Two more panels had been added to the cantilever span at the actual time of collapse and the false work of the anchor arm removed.)

The Staffs of the Different Corporations.—There were four parties directly interested in the building of the bridge—viz., the Canadian Government, the Quebec Bridge and Railway Company, the Phœnix Bridge Company, and the Phœnix Iron Company. Each had its own staff to take charge of the portions of the work in which it was interested.

The Dominion Government was represented by the Deputy Minister of the Department of Railways and Canals and his assistants; two Deputy Ministers and three inspectors having been connected with the work.

The Quebec Bridge and Railway Company maintained in its service and employed on the work a chief engineer, a consulting engineer, two erection inspectors, and four mill and shop inspectors. The chief engineer, Mr. E. A. Hoare, M. Inst.C.E., had an extensive experience as a railway engineer, and had done most of the company's preliminary work. Mr. Hoare had a high reputation for integrity, good judgment, and devotion to duty, but there is, however, nothing in Mr. Hoare's record that would indicate that he had the technical knowledge to direct the work in all of its branches. The company's directors do not seem to have realised the importance of the duties pertaining to Mr. Hoare's position and, while believing that he was not competent to control the work, they still gave him the position, the powers and emoluments of the office of chief engineer.

Mr. Theodore Cooper, of New York, was the consulting engineer. In the extent of his experience and in reputation for integrity, professional judgment, and acumen Mr. Cooper had few equals on this continent, and his appointment would have been generally approved. Mr. Cooper's strict duties were to examine, correct, and approve the plans prepared by the contractors and to give engineering advice to Mr. Hoare when requested. Mr. Cooper and his chief assistant, Mr. Bernt Berger, carried on a most thorough and painstaking examination of the plans. Mr. Cooper appointed both shop and erection inspectors for reasons explained in his evidence, and had these inspectors report fully and regularly to him. Mr. Cooper states that he greatly desired to build this bridge as his final work, and he gave it careful attention. His professional standing was so high that his appointment left no further anxiety about the outcome in the minds of all most closely concerned. As the event proved, his connection with the work produced in general a false feeling of security. His approval of any plan was considered by every one to be final, and he has accepted absolute responsibility for the two great engineering changes that were made during the progress of the work—the lengthening of the main span and the changes in the specification and the adopted unit stresses. In con-

sidering Mr. Cooper's part in this undertaking, it should be remembered that he was an elderly man, rapidly approaching seventy, and of such infirm health that he was only rarely permitted to leave New York.

Mr. Cooper assumed a position of great responsibility and agreed to accept an inadequate salary for his services. No provision was made by the Quebec Bridge Company for a staff to assist him, nor is there any evidence to show that he asked for the appointment of such a staff. He endeavoured to maintain the necessary assistants out of his own salary, which was itself too small for his personal services, and he did a great deal of detail work which could have been satisfactorily done by a junior. The result of this was that he had no time to investigate the soundness of the data and theories which were being used in the designing and consequently allowed fundamental errors to pass by him unchallenged. The detection and correction of these fundamental errors is a distinctive duty of the consulting engineer, and we are compelled to recognise that in undertaking to do this work without sufficient staff or sufficient remuneration both he and his employers are to blame. But it lay with himself to demand that these matters be remedied.

During the construction of the substructure, Mr. Cooper visited the bridge site on several occasions, but did not visit the bridge during the erection of the superstructure. He visited the Phœnix Iron Company's shops but three times during the fabrication of the structure.

During erection Mr. Cooper upon receipt of information from Mr. McClure, ordered certain work on the erection to be stopped for correction; this order was communicated by him to Mr. Hoare, who stopped the work accordingly.

The designing engineer was Mr. Szlapka, who had received a thorough technical education in Germany and has been with the Phœnix Bridge Company for about twenty-seven years, having held his present position for twenty-one years. Previous to 1903 his ability as a designer had been thoroughly tried, and his experience was wide. As usual in present bridge company organisations Mr. Szlapka's work was being confined to his own department, and his personal knowledge of the work of transportation and erection is limited. The evidence shows that Mr. Cooper, whose faculty of direct and unsparing criticism is well known, had every confidence in the ability of Mr. Szlapka, and on previous works had had good opportunity to form his estimate of him. Mr. Szlapka was responsible for the entire work of designing, and the Commissioners are satisfied from their personal investigations at Phœnixville that this was conducted with care and energy. Mr. Szlapka's mistakes and errors, to which the disaster is directly attributed by the Commissioners, are discussed elsewhere.

Development of the Plans.—The first preliminary plan of the Quebec Bridge was made by the Phœnix Bridge Company for the Quebec Bridge Company, and is dated November 30, 1897. A second plan was made on December 7, 1897, showing the lower chord curved. In response to our inquiry Mr. Szlapka states that the change from the straight to the curved lower chord was made for the sake of artistic appearance, either form being considered by him structurally satisfactory.

There are three other plans, dated February 17, 1899, two of which show the lower chord of the anchor arm arched only at both ends, and the other shows the anchor arm arched only at the main pier. In general outline this last plan was almost identical with that of the final design.

All of these five general preliminary plans are drawn for a river span of 1,600 ft. The plan of November 30, 1897, shows the cross section of the river correctly, which indicates that information of this nature had been received from the Quebec Bridge Company prior to that date.

When the details for the anchor arm were completed and those for the cantilever partially completed the weights of all details were calculated and final anchor arm stress sheets computed. This was the beginning of the shop drawing period; only the anchor towers had then been shop detailed.

The dead load concentrations upon which the final make-up of the members of the anchor-arm was based were as follows:

Half-suspended span	4,842,000 lb.
Cantilever-arm.....	13,205,200 ,,
Anchor-arm	13,317,600 ,,

The corresponding concentrations, as determined on June 25, 1907, were found to be:

Half-suspended span	5,694,000 lb.
Cantilever-arm	15,804,000 ,,
Anchor-arm	17,318,000 ,,

The total steel in the latter concentrations was about 35,316,000 lb.

The difference between these two sets of concentrations indicate a fundamental error in the calculations for the bridge. In a properly computed bridge the assumed dead load concentrations upon which the make-up of the members is based should agree closely with the weight computed from the dimensions in the finished design and with the actual weights.

In computing the make-up of the members of the cantilever-arm the same dead load concentrations were assumed for the cantilever-arm and for the suspended span as in the computations for the anchor-arm, and the above comment will apply with equal force to the design of the cantilever-arm.

The failure to make the necessary recomputations must be attributed mainly to the overconfidence of Mr. Szlapka in the correctness of his assumed dead load concentrations. Mr. Cooper shared this confidence since he approved the stress sheets.

Transportation and Erection.—In the design of the bridge a normal configuration and load-

ing was assumed in which the stresses in all the members were intended to be axial. In other words, under these conditions no bending stresses would exist at the various joints: under any other loading, therefore, angular changes would either take place or tend to take place at the joints; that is to say, bending stresses would exist.

The shop lengths of all members being computed so that in the normal configuration the members had the normal lengths, it resulted that during erection, when the members were under little or no stress, the whole configuration was distorted, as compared with the normal configuration. The falseworks upon which the anchor-arm was built had therefore to be arranged to conform to the initial configuration. After the anchor-arm was erected the building of the cantilever-arm gradually introduced and increased the stresses in the various members of the anchor-arm, and at a certain stage the anchor-arm became free from the camber blocks on the falsework, which were lowered to assist this movement.

In the original distorted form all field butt joints were in contact only at one edge, since in the normal form they would be in full contact. With the increasing loads on the cantilever-arm, due to the progress of erection, these joints gradually approached the condition of full contact and in doing so revolved about the edges in contact; in the meantime the splices were secured by bolts which could be changed, as the movement at the joints improved the matching of the holes. The instructions issued by the Phœnix Bridge Company were that when the joints finally closed the splices should be permanently riveted.

It must be apparent that during the movement in question the stresses at these joints were applied first only at the edges in contact, and that it was not until the joints were fully closed that there was any possibility of uniform distribution of stress. Indeed, this condition was not possible until the bridge would be completed and carrying its normal load, and the attainment of this condition would even then be dependent on the accuracy of the mechanical work at the joints.

The camber movements were regularly and carefully observed by the Phœnix Bridge Co.'s engineer in charge of survey work, and Mr. Deane states that these observations agreed closely with the expected movements as calculated by the designing engineers.

There can be no doubt that the camber problem in the Quebec bridge was much more difficult than in ordinary structures on account of the magnitude of the bridge and the great size of its members.

Difficulties during Erection and Events at the time of the Collapse—Chord A 9-L*—In April, 1905, this chord had a severe fall while being handled in the Chaudiere yard. The drop was 5 feet at one end and about 3 feet at the other. The chord struck in such a way that any resulting bend would have been at right angles to the deflections measured on August 27, 1907. Two lower flange angles were broken. This chord was repaired in July, 1905. We have examined these repairs since the fall of the bridge, and we find nothing to justify us in connecting them with the disaster. Whether the chord was strained by its fall so that it afterwards bent more readily under stress is a matter of conjecture that cannot be settled.

The difficulties with the lower chords that finally resulted in the collapse of the bridge were noted early in the season, but those first observed were considered to be of no minor importance. The joints between lower chords 5 and 6, anchor-arm, remained open $\frac{1}{16}$ in. on the lower side, long after the others had closed. They finally closed shortly before the disaster, and on August 29 were being riveted. No explanation has been offered of the slow closing of these joints. Trouble arose afterwards with joints between chords 7 and 8 of the west truss of the south cantilever arm the ribs of these chords being bent, so that a full and proper bearing could not be obtained, the bends in the opinion of Mr. McClure (McClure to Cooper) occurring since that chord had been under stress, and were not present when the chords were placed.

It is plainly indicated that no one except Mr. Cooper looked upon this matter as serious or as indicating any constitutional weakness. The bends at 7 and 8 were reported on August 6th, the bends at 8 and 9 discovered on August 12th, and that both bends were in the west truss; that previously from time to time chords with ribs more or less wavy had been reported

On August 20th, it was discovered that chord 8-R of cantilever arm was bent, and afterwards found that 9-R and 10-R also showed distortion. Mr. McClure was ill and did not see these bends until several days after they were found (August 23rd). On August 23rd, the joint at chords 5 and 6-R of cantilever-arm was found to be off on one centre rib $\frac{1}{2}$ in. at bottom, the off-set running to nothing at top. Mr. Kinloch visited chord 8-R daily for several days and imagined that the bend was becoming greater, all four ribs being bent, but not alike.

The bend in chord 9-L anchor-arm was discovered about 9.30 a.m. August 27th, to have greatly increased, it having been previously noted and being under observation. The bend had increased from $\frac{3}{4}$ in. to $2\frac{1}{4}$ in. in one week.

On this date the deflections of the suspicious chords were measured and it was recognised that they were face to face with a crisis.

Wednesday August 28th, was a day of waiting and uncertainty. . . . men were uneasy and alarmed and the officials were anxiously waiting instructions from Phœnixville or New York.

* The first to fall.

Some measurements were made to test the stability of the main pier, but no one seems to have thought of testing the span for alignment or levels, and above all to measure the chords again to see if they showed any increase in deflection.

At Phœnixville, on August 29th, it was decided that it was safe for the work to proceed, whereas Mr. Cooper, after a brief discussion with Mr. McClure who had been despatched to New York to report, wired to Phœnixville that no more load should be added to the bridge. The bridge fell that afternoon.

Conclusion.—As a conclusion reached from the evidence and from our own studies and tests, we are satisfied that the bridge fell because the latticing of the lower chords near the main pier was too weak to carry the stresses to which it was subjected, but we also believe that the amount of those lattice stresses is determined by the deviation of the lines of centre of pressure, from the axes of the chords, and this deviation is largely affected by the conditions at the ends of the chords. We must therefore conclude that although the lower chords 9-L and 9-R anchor arm, which, in our judgment, were the first to fall, failed from weakness of latticing, the stresses that caused the failure were to some extent due to the weak end details of the chords, and to the looseness or absence of the splice plates arising partly from the necessities of the method of erection adopted, and partly from a failure to appreciate the delicacy of the joints and the care with which they should be handled and watched during erection. We conclude from our tests that owing to the weakness of the latticing, the chords were dangerously weak in the body for the duty they would be called upon to do. We have no evidence to show that they would have actually failed under working conditions had they been axially loaded and not subject to transverse stresses arising from weak ends, details, and loose connections. We recognise that axial loading is an ideal condition that cannot be practically attained, but we do not consider that sufficient effort was in this case made to secure a reasonable approach to this condition. The Phœnix Bridge Company showed indifferent engineering ability in the design of the joints and did not recognise the great care with which these should be treated in the field.

Our tests have satisfied us that no temporary bracing such as that proposed by Mr. Cooper could have long arrested the disaster; struts might have kept the chords from bending, but failure from buckling and rivet shear would soon have occurred.

Unsinkable and Uncapsizable Ships.*—It is only since the terrible loss of H.M.S. *Victoria* by capsizing—a disaster

* Gen. Goulaeff, F.R.S.N.A. (Proceedings Institution Naval Architects. Abst.).

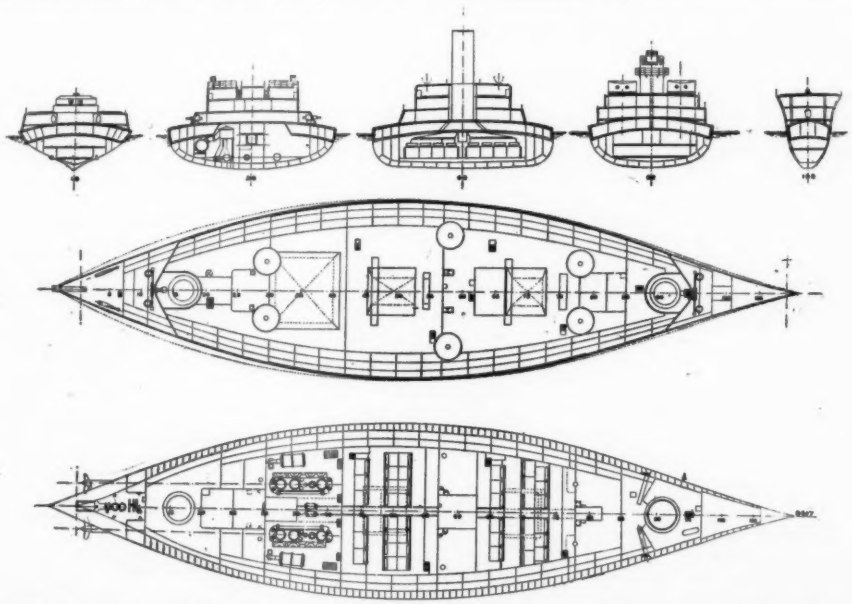


FIG. I.—GENERAL ARRANGEMENT OF AN IRONCLAD OF SOME 17,220 TONS DESIGNED ON THE GOULAEFF FORM AND SYSTEM OF CONSTRUCTION.

repeated in several cases during the late Russo-Japanese naval war—that it has at last been recognised that as soon as a ship of the present ordinary form, proportions and system of construction receives a blow either by ram, torpedo, shot or collision, perforating the underwater part of the hull and causing more or less serious injuries, the vessel immediately heels dangerously over and loses her stability. Ever since the loss of the *Victoria*—that is, for more than ten years—I have thought how to solve this problem in the most practical manner, and it is the results of my work in this direction that I wish to bring before the Institution of Naval Architects.

In the proposed system of construction, comprising, as will be seen from the description, some modification of the form and proportions of vessels, I have endeavoured to protect the ship against the torpedo by the internal system of construction of the hull.

I have attained this purpose by making vessels much broader than they have been, or are at present, leaving their length the same, or making them even somewhat longer. This form and system of construction provides treble broad longitudinal cellular side corridors, which are rendered possible by the increased breadth of the vessel, and are intended to reduce to a minimum the quantity of water that may enter the ship through injuries or openings made in her underwater skin. Fig. 1 gives a general idea of the transverse sections and plans of hold of a ship of this system of construction. The increase of breadth is made at the expense of the draught of water, so much so that the ratio $\frac{B}{D}$ amounts to about 4·5, instead of 2 to 3, as in vessels of ordinary form and proportions. The displacement is practically the same as that of a ship of ordinary form, with which the comparison is made. In the wide treble side there are safety longitudinal corridors, shown in Fig. 1, surrounding nearly the whole length of the vessel, and I propose to have, as far as practicable, no water-tight or other kind of doors, but only the smallest possible permanently-closed boiler manholes, for the purpose of giving access to the cellular compartments from the top. The radius of action of the

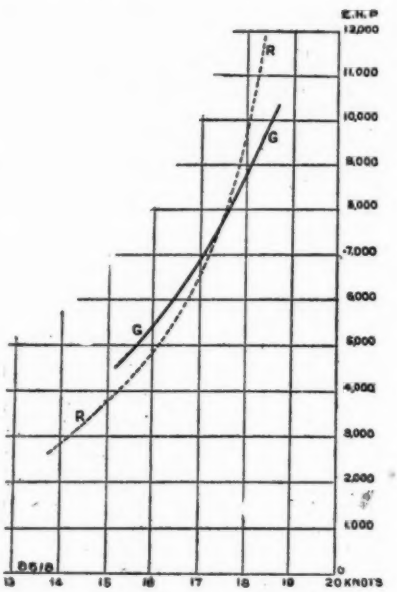


FIG. 2.—THESE CURVES OF THE E.H.P. REFER TO THE DISPLACEMENT OF 14,266 TONS OF THE IRONCLADS, G.G. OF THE GOULAEFF TYPE AND R.R. OF H.I.M. IRONCLAD "RETVIZAN" OF AN ORDINARY FORM.

modern torpedo, inside a vessel, counting from the outer skin inwards, being about 18 ft., I propose to make the width of the cellular side corridors about 18 ft., that is 6 ft. for each corridor. Thanks to this, all the internal vital parts of the ship, especially those liable to explosion, such as steam boilers, magazines, shot and shell rooms, and torpedo storerooms, &c., are removed from the outer skin for a distance of about 18 ft. inwards on each side towards the centre of the vessel, thus very efficiently securing their greater safety from any outside explosion, or any other mode of attack.

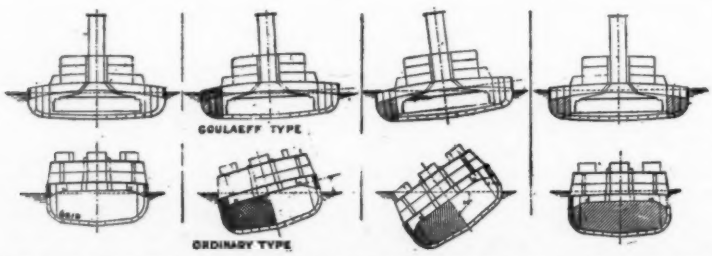


FIG. 3.—RESULTS OF THE CALCULATIONS OF THE COMPARATIVE ANGLES OF HEEL OF AN IRONCLAD OF THE GOULAEFF TYPE, AND OF AN IRONCLAD OF THE SAME DISPLACEMENT OF AN ORDINARY FORM AND SYSTEM OF CONSTRUCTION.

In larger ships I would suggest having this distance increased to about 20 ft.

When, in 1896-1897, I brought forward my proposal for such ships, I was met by the criticism that the resistance of water to the progress of such broad vessels at any high speed would be altogether too great. But, knowing the results of the late Mr. W. Froude's investigations of broad and shallow forms, I felt sure that I was right, at least in this respect. Fig. 2 shows a curve *R R* of the resistance, or of effective h.p. at different speeds from 13 to 20 knots, of the Russian ironclad *Retvizan* of ordinary form and proportions, compared with a similar curve *G G* for an ironclad of my own form, and of the same displacement. This diagram, as well as others also described, were based on the results of model experiments which had been made in the St. Petersburg experimental tank. Fig. 2 shows that, whilst the displacement of both vessels is the same (14,266 tons), the i.h.p. of engines required to drive a ship of the *Retvizan* shape at a speed of 18 knots amounts to 23,600, whilst the i.h.p. required to drive a ship of the broader and shallower form, at practically the same speed of 18·42 knots, amounts only to 19,412, and this difference in favour of the broader vessel increases if the speed be further increased.

Ships of my proposed system of construction possess, as compared with ordinary ones, incomparably greater unsinkability and uncapsizability under the effects of torpedoes, shot, rams, and collisions with other ships. The following table will illustrate this point:-

TABLE I.

—	Displacement, 17 220 tons.	
	Ironclad of the Goulaeff Form and System of Construction.	H.I.M. Ironclad *Emperor Paul I.* of ordinary Form and System of Construction.
Angles of heel under the same conditions of underwater injuries made by torpedoes. Extent of injuries, lengthwise 60 ft.,	2 deg. 40 min.	14 deg.
Angles of heel under the same but still more extensive and severe underwater injuries made by torpedoes. Extent of injuries, lengthwise, 170 ft.	6 deg. 50 min.	50 deg.

From the above table it is evident how much more moderate an angle of heel a ship of my form takes as a result of underwater injuries to the hull, compared with an ordinary ship of the same size, under exactly the same conditions. At the last angle of heel given in the table (30 deg.) of the ironclad of ordinary form, her side turrets enter the water, and the vessel herself becomes immersed to a draught of 33·25 ft. by the bow and 36·12 ft. by stern, with a still further increase in the quantity of water inside of her, pouring in through the above-water ports and through possible openings made by artillery fire in her sides, and spreading along the interior of the 'tween decks, causing her to lose more and more of her stability, until she finally capsizes. Whereas, under the same conditions, as shown in Fig. 3, an ironclad of my form, after being struck even by several torpedoes still remains perfectly able to fight her guns or to proceed under her own steam to her destination. The comparative smallness of her angle of heel is shown in Fig. 3, representing the results of extensive calculations of the stability of both vessels, with some compartments (those shaded on the drawing) filled with water, the extent of the underwater injuries sustained being taken lengthwise at 60 ft. and 170 ft., with a radius of destruction of the torpedo 18 ft. inwards. The adoption of this system of construction in mercantile steamers would, therefore, enormously increase their safety in case of collision, and would consequently reduce the rates of insurance required by underwriters. My form and system of construction would not only satisfy this condition, but would greatly reduce the number of cases of ships grounding on shallows or rocks, thus offering additional security for navigation in shallow seas and intricate channels. Increased breadth ensures so much additional internal capacity that great quantities of fuel or other cargo may be stowed on board such ships as compared with ships of ordinary narrow form, and this favours the adoption of such ships either for distant cruising purposes or for carrying a large cargo in hold, and passengers above in the central upper structure. The safety cellular corridors so effectively isolate all the vital parts and stores of the ship liable to explosion and ignition, such as magazines, torpedo storeroom, &c., from the outer skin of the vessel, that the blowing up of these by detonation from the explosion of an enemy's torpedo or mine outside in the vicinity of these parts is most efficiently prevented.

The Efficiency of Boiler Heating Surfaces.—At a recent meeting of the Civil and Mechanical Engineers' Society Mr. C. H. Wingfield, who as chief of Thornycroft's engineering department, has been identified so prominently with the development of the water-tube boiler, read a paper on the above subject. One of the greatest popular fallacies, Mr. Wingfield considers, is the belief that the rate at which heat passes from the hot gas to the water in a boiler varies directly as the difference between temperatures. This idea probably originated in a misinterpretation of Rankine's statement that "the rate of

conduction through a flat layer of uniform thickness is simply proportional to the difference between the temperatures of the two faces of the layer and inversely to its thickness." Rankine was speaking of what happened in the substance of the plate after the heat had entered it, and during its passage through it. He did not refer to the difficulty with which heat leaves hot gas and enters the plate; a difficulty owing to what may be called "surface resistance." The nature and exact reason for the existence of this surface resistance is very obscure. One suggestion which has been made is that after giving up part of its heat a layer of gas remains in contact with the heating surface, and serves as a non-conducting lagging, which impedes the transfer of heat by conduction from the hot gas, although not interfering with the passage of radiant heat. Fletcher found that pieces of paper attached to the dry side of a furnace plate did not char. Sir John Durston proved experimentally that 90 per cent. of the whole resistance occurred on the dry side of the plate. But the author is disposed to believe that, while some of the resistance may be due to a film of air, the greater part is an inherent quality of the plate itself. Another popular fallacy is that any heat-absorbing surface, such as that of a water-tube, is necessarily more efficient if the flame and gas beat on it transversely than if they move longitudinally. The true law of the transfer of heat between gas and water is given, he said, by Rankine in the formula:—

$$Q = \frac{(T - t)^2}{a}$$

where Q = units of heat transmitted by one square foot per hour, T = temperature of the gases, and t = that of the water. The denominator a is an empirical constant varying between 160 and 200. The main point is that Rankine's formula points to a square law, and shows that the rate of transmission varies as the square of the differences. Blechynden and others have confirmed this. One curious conclusion to which his experiments led Mr. Blechynden was that copper, after being in use for some time, transmitted less heat than steel, although the latter is comparatively a poor conductor of heat. The inference is that the surface resistance is the cause of this loss of efficiency, and that a film of copper oxide offers more resistance than a film of iron oxide. Mr. Wingfield said that he had got good results from the following modification of Rankine's formula for the evaporative efficiency of a boiler:—

$$W_e = BE - \overline{W}_a \times A.$$

Here W_e denoted the pounds of water evaporated per hour reduced to from and at 212°. W was the weight evaporated in pounds (from and at 212°) per square foot of heating surface; whilst A and B were constants depending on the design of the boiler.

Improved Slide-Rule with Magnifying Cursor.

We have received from Messrs. A. G. Thornton, Ltd., St. Mary's Street, Manchester, a new slide rule, which, while retaining the ordinary scales, has some additions designed by Prof. Perry, for the evaluation of expressions involving fractional indices; that is of calculating A^n say $3{\cdot}7^{1{\cdot}41}$, hence of use in steam and gas engine work and for hydraulic and electrical calculations. This result was originally accomplished by adding to the rule a scale graduated in divisions proportioned to the log log of the numbers from 2 to 1,000, and so to read off the logs of numbers to any base. The new scales, however, displaced the lowest, or D scale of the ordinary rule, which met with disapproval on the part of those accustomed to work with the C and D scales. It is to meet this difficulty that the rule now noticed was introduced, as, in this new model, not only has the D scale been retained but the log log scale has been greatly extended. This improvement has been effected by making the rule slightly wider and placing the log log scale along the top and bottom edges.

Another improvement introduced in this model consists in the provision of a magnifier carried on the cursor, the magnifying power of the lens being about 2. Hence the divisions can be read with all the clearness possessed by a 20 in. rule, and with the advantage of securing greater relative accuracy in the result, for the larger rules do not usually increase in accuracy in proportion to their size owing to unequal shrinkage, &c. The magnifier can be thrown out of action when it is desired to use the rule in the ordinary way and where less accurate results are required. The bevel edge of the rule is graduated in inches and $\frac{1}{20}$ths, the cursor having a pointer attached to facilitate readings. The instrument is $10\frac{5}{8}$ in. long thus permitting the cursor to work firmly at the two extremities of the rule.

ELECTRICAL PROGRESS

By ANDREW STEWART, A.M.I.E.E.

The Cost of Operating Petrol-Electric Omnibuses.

In our March issue we described and illustrated the petrol-electric omnibus, which Messrs. Tilling have in service between North and South London. Some further details concerning the efficiency and general performance of these vehicles were made public in a paper read to the Society of Road Traction Engineers, by Messrs. Smith and Stevens, the former Messrs. Tilling's chief engineer, the latter the maker of the omnibus.

The electrical gear, as is well known, takes the place of the gear box and differential; and, by reason of its flexibility, obviates much of the wear and loss of power which takes place in these mechanical devices. No measurements of the efficiency of a petrol vehicle equipped with mechanical transmission appear to have been put before the meeting, but the efficiency of a petrol-electric combination, the vehicle weighing 7 tons, is about 70 per cent., engine to road wheels, on a grade of 1 in 12, using a 16-1 gear ratio. With the smaller gear ratio of 12 to 1, an efficiency of 67 per cent. is recorded under the same conditions.

The torque exerted by the motors is constant for a given current, a characteristic of all electric motors. On the motors used, the torque varied from about 20 lbs. at 20 inches radius, with 58 amps. to 140 lbs. with 222 amps.

The authors appear to be particularly unfortunate in their comparison between an electric tramcar, and a petrol-electric vehicle, for they give the latter a very high position, placing it ahead of the tramcar, because the total electrical load on the dynamo and motors is limited by the power of the engine, and as these are capable of withstanding 300 per cent. overload, a burn out through excessive load is impossible; whereas a tramcar driver, having all the resources of a large station to draw upon, may throw the motors on to the circuit suddenly, and thus burn the armatures out.

A very superficial acquaintance with electric traction would have enabled the authors to see that if a tramcar driver did this on a level road, the jerk due to the rapid acceleration would dissipate for ever any notion of further experiments in the same direction; while if the attempt were made on a grade, the wheels would slip; but in neither case would the armatures be burnt out.

Moreover this 300 per cent. overload capacity, which the authors claim as an advantage, costs money. It simply means that the equipment is so much larger than it would be if this overload capacity had been absent. It is nearly analogous to putting in a 10 h.p. steam engine when you only want 5 h.p., and saying that you have 100 per cent. overload capacity.

A petrol-electric vehicle is like an electric tramway, except that the former carries its power station about with it, 300 per cent. overload capacity and all, and we leave our readers to judge whether it is more economical to run a transit system with several hundred small power stations each of about 30 h.p., shaken about on the vehicles they drive, or one large one, not necessarily aggregating the horse power of all the small stations, operating under more favourable conditions. The petrol-electric road vehicle, while it saves the cost of rails, has the disadvantage of requiring far more power to drive it, and there is no difficulty in reaching the point where traction on rails with a single economical power station, even when handicapped with the capital cost of the permanent way, shows an appreciable

saving over the vehicle which runs on common roads.

From the authors' very full tables we gather the following data. To this we have added the costs on a typical electric tramway using cars having approximately the same carrying capacity. The London County Council tramways cannot be used for this comparison, their capacity being more than twice that of Messrs. Tilling's petrol-electric omnibus; moreover they have been purchasing energy from an outside source at a pretty high price. Most of the other tramways in and round London have equally large rolling stock, but the Glasgow Corporation, who have a large system, use cars of nearly uniform capacity, and the figures for this system are added:—

TABLE I.

—	Petrol.	Petrol-Electric.	Electric Tramway.
	d.	*d.*	*d.*
Maintenance	2·443	1·0	1·4 (includes track renewals)
Tyres ...	1·75	1·75	—
Petrol ...	1·32	1·25	·3 electric power at car
Other items	6·417	5·18	4·02
Total cost per car or bus mile ...	11·93 pence.	9·18 pence.	5·72 pence.

Owing to the difference between the accounting of the authors of the paper and standard tramway accounts, no further comparison in detail is possible, but the authors have evidently a long way to go before they can challenge the electric tramway.

The type of apparatus that will ultimately beat the electric tramway, will not be a miniature central station mounted on wheels; nor will any combination of dynamos and motors having 300 per cent. overload capacity solve, in an economical fashion, a problem that is peculiar to London, and one that is likely to remain so, for what other city would leave the transport problem to lumbering road vehicles propelled by boxes of rattling machinery?

Electric Canal Haulage.

The Royal Commission on our canals still sits, endeavouring no doubt to hatch out a satisfactory solution of the problem of internal transport on our neglected waterways. Similar, though more advanced, problems are being dealt with by Germany and the United States, both these countries being actually engaged in evolving a satisfactory method of mechanical haulage for their waterways.

We have already dealt with several American and German efforts in this direction. The latest contribution to our knowledge of the subject being a paper by Messrs. Stillwell and Putnam to the American Institute of Electrical Engineers, dealing with tests made on electrically operated tractors. The tractors used were the proportional adhesion tractor, and the ordinary small electric locomotive running on the towing path. Both these systems have already been dealt with in this column.

The object of the experimenters was to find the pull required for canal boats at various speeds, the merits of the two types of tractor, the best speed and length of tow, the power required, and the best equipment.

The experiments were carried out on the Lehigh Canal, Pennsylvania, and one part was equipped with tractors of the ordinary mining locomotive type on a 42 in. gauge. Another part had proportional adherence tractors running on 10 in. I beams.

The results of the tests to determine the tow rope pulls are given in Table 2:—

TABLE II. TESTS OF PULL ON TOW ROPE.

Barges and State of Load.	Total Load Towed.	Average Speed.	Effective Pull.
	English tons.	Miles per hour.	lbs.
Four boats loaded ..	487	2·98	2,200
Two " " ...	243	3·62	1,500
One boat " ...	122	4·0	1,000
Four boats empty ...	84½	4·0	1,010
Two " " ...	42	4·2	560
One boat " ...	21·2	5·0	400

From these experiments the authors deduce the formula $\cdot 45 \times V^2 \times T$, where V is the speed in miles per hour, and T the total load towed in American tons, as the effective tow rope pull required for any number of loaded barges. For empty barges this formula becomes $\cdot 67 \times V^2 \times T$. These are approximately correct for these two conditions of load. For partially loaded barges the following formula is given:—

$$\cdot 67 - \frac{\cdot 22 \times \text{net load per boat}}{113} V^2 T$$

No facilities were available for determining the effect of varying the cross section of the barge in its relation to the section of the canal, but during the tests the loaded boats presented an immersed

cross section of 54 sq. ft., the canal itself having a section of 440 sq. ft.

The acceleration tests gave from ·024 miles per hour per second for four loaded barges to ·109 miles per hour per second for an empty barge.

The tractor efficiency tests yielded some interesting figures, and demonstrated that the ordinary locomotive running along the bank on rails was more efficient than the proportional adhesion tractor on an I girder. The figures were as follows :—

TABLE III. EFFICIENCY OF TRACTORS.

—	Effective Pull. 1,000 lbs.	Effective Pull. 2,000 lbs.	Effective Pull. 3,000 lbs.
	Per cent.	Per cent.	Per cent.
Mining type locomotive	80	83½	84
Proportional adhesion tractor, A	68	73·3	74·8
Proportional adhesion tractor, B	73	77·2	77·5

Tractor *A* was of American make, tractor *B* of French make.

The effective pull was that developed at the tow line, and all pulls are corrected to effective pull in the direction of motion. The authors think that the efficiency of tractors of the locomotive type might be still further improved by (a) an increase in the size of the wheels; (b) a longer wheel base with small flange clearances; (c) such a mechanical construction as will permit of all bearings being in perfect alignment under all conditions of operation; (d) selecting the point of rope attachment so that flange friction will be reduced; (e) follow railway practice as far as practicable in constructing the track, and in the mechanical details of the tractor, especially with regard to the oiling arrangements.

Five miles per hour is considered the upper limit of speed for canal towage, but much depends on the ability to steer the boats. The "Erie" steering gear, whereby the last boat is used as a rudder was found very satisfactory. It is illustrated Fig. 1 where the gear for manipulating the last boat as a rudder is clearly shown.

Further experiments showed the watt hours per ton mile to be as under:—

From the table it appears that the cost of hauling goods in a train of loaded barges is about ·012 pence per ton mile, while an empty barge can be towed at a cost of ·08 pence per ton mile, these figures being based on electricity at 1*d*. per unit, which is the usual power charge in this country. Such figures indicate that the cost of goods transport on canals is a mere fraction of the cost by any other system if up to date methods are employed.

Electricity in Plant Culture.

Our readers are no doubt aware that there is a wide and probably profitable field

TABLE IV.

SPEED, KILOWATT INPUT, AND WATT-HOURS PER TON-MILE. AVERAGE RUN 1·52 MILES—TWO-BOAT LOCKS. TIME LOCKING: 4 BOATS 35 MIN.; 2 BOATS 15 MIN.; 1 BOAT 10 MIN.

	Speed.		Mining Locomotive.		Tractor.	
	Maximum speed miles per hour.	Average speed including locking miles per hour.	Average input at trolley kilowatts.	Watt-hours per ton-mile.	Average input at trolley kilowatts.	Watt-hours per ton-mile.
Direct current.						
4 boats loaded	3·00	1·40	8·7	11·3	8·8	12·0
4 boats empty	4·00	1·60	4·3	29·2	4·6	30·3
2 boats loaded	3·45	2·22	9·1	14·8	9·3	15·5
2 boats empty	4·57	2·65	5·2	41·9	5·4	44·0
1 boat loaded	4·00	2·81	7·7	20·0	8·0	21·0
1 boat empty	5·30	3·42	4·9	61·0	5·2	64·5
Alternating current.						
4 boats loaded	2.88	1·37	8·1	11·0	8·2	11·1
4 boats empty	4·13	1·59	5·0	33·5	5·3	34·8
2 boats loaded	3·45	2·22	9·6	15·5	9·9	16·0
2 boats empty	4·98	2·78	6·6	50·8	6·8	53·0
1 boat loaded	4·19	2·90	9·0	22·6	9·4	23·3
1 boat empty	6·00	3·67	6·7	77·0	6·9	80·8

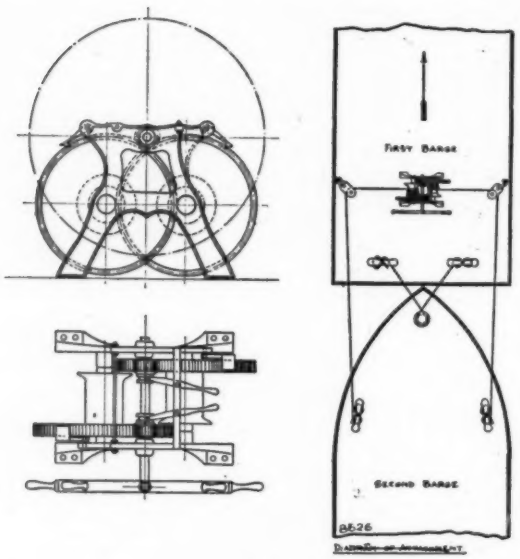


FIG. 1.

for investigation in the application of electricity to the propagation of plants.

In a recent paper to the Naturalists' Society, Mr. J. H. Priestley, B.Sc., dealt at considerable length with this subject. It appears that the earliest experiments date back to 1749, but during the last three or four years experiments, on a large scale, have been carried out near Bristol, at Gloucester, and elsewhere.

In all cases the electricity was not applied to the soil direct, as in some earlier experiments, but high tension currents were distributed by wires over the area under treatment, and the current discharged from points towards the ground. In such cases the current would amount to a mere fraction of one ampere, at a pressure of many thousand volts, and there would be a steady, but silent, discharge of electricity from these points towards the ground, travelling no doubt *viâ* the stalks of the plants. Whatever may be the theory propounded to account for the influence of the electric current, there appears to be no doubt that certain plants benefit considerably.

The comparison was made by having large adjacent plots equally well treated as regards manure, water, and light, but unprovided with these electrical discharge points. The results are summarised as follows:—

TABLE V.—TESTS OF ELECTRICALLY INFLUENCED PLANTS.

Cucumbers	gave	17 per cent. increase.
Strawberries	,,	36 per cent. increase for 5 year old plants and 80 per cent. for 1 year plants.
Broad Beans	,,	15 per cent. decrease; ready 5 days earlier.
Celery	,,	2 per cent. increase.
Tomatoes	,,	No difference.
Beet	,,	33 per cent. increase.
Carrots	,,	50 ,, ,, ,,
Canadian Wheat	gave	39 ,, ,, ,,
English Wheat	gave	29 ,, ,, ,,

A remarkable feature of the beet crop was that in addition to the extra total yield of the electrified portion, the root gave 8·8 per cent. total sugar, while the unelectrified yield was 7·7 per cent. sugar. It appears therefore that, taking the cumulative effect of the larger crop, and the larger percentage sugar per root, there must be vast possibilities in the electrical propagation of sugar beet.

Another feature was that the electrically treated wheat sold at 7½ per cent. better prices, as it seemed to produce a better flour. This was subsequently verified by Mr. J. Kirkland, of the National School of Bakery, Borough Polytechnic, London, who found that the average of dry glutens were from the electrified portion 11·15 per cent., and from the unelectrified portion 10·35 per cent.

Experiments were cited by the author of the paper, using earth currents of low pressure, which, while improving the crop,

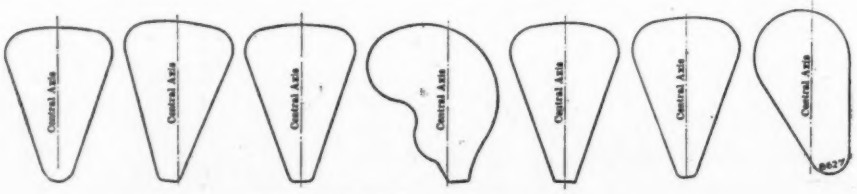


FIG. 2.—BLADES FOR FANS A, B, C, D, E, AND F.

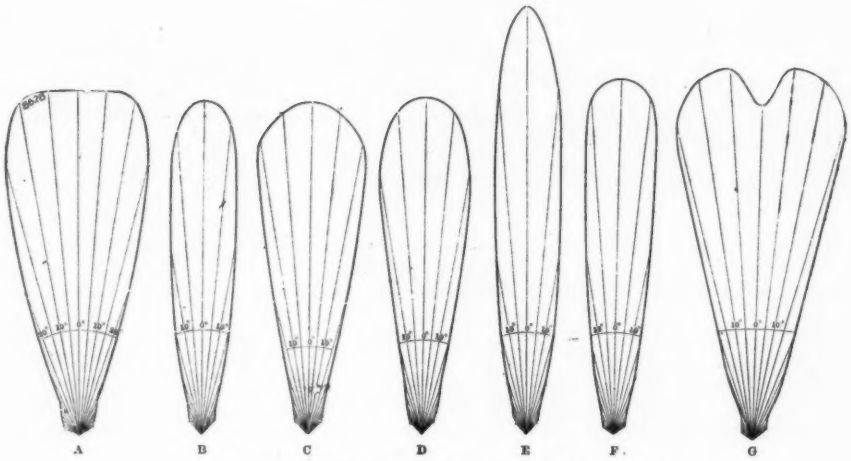


FIG. 3.—DISTRIBUTION OF AIR FROM FANS A, B, C, D, E, F, AND G.

did not result in such a marked improvement as those already noted, using atmospheric currents, though this method does not appear to have had the same thorough trial as the atmospheric system.

Tests of Electrically-Driven Propeller Fans.

Of all the appliances used by the engineer, the fan is most generally misunderstood. As an example, the writer had an enquiry for a large electrically-driven fan to a specification drawn up by an eminent firm of engineers. On going into the matter it was found, first, that the type of fan specified would not do the work required, second, that with no known fan would the results specified be obtained. It is surely unnecessary, therefore, to apologise for reviewing, briefly, a series of experiments carried out on small propeller fans at the University of Texas by Mr. A. C. Scott, and outlined in a recent issue of *The Electrical World* (New York).

Seven different fans having blades shaped as shown Fig. 2, were tested; all had four blades, and the total volume of air delivered was found to vary as follows, reading from left to right.

The figures cubic feet of air per net watt give the output, after the losses in the motor had been deducted, and represent roughly the relative efficiency of the fan blades, apart from the motor.

The mechanical data of the fan blades were as shown in Table VII.

The distribution of the air stream varied considerably. See Fig. 3, where the diagrams are in the same position as the blades, Fig. 2.

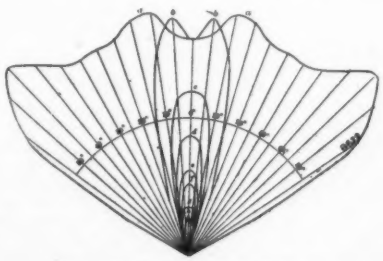


FIG. 4.—VELOCITY OF AIR FROM FAN A.

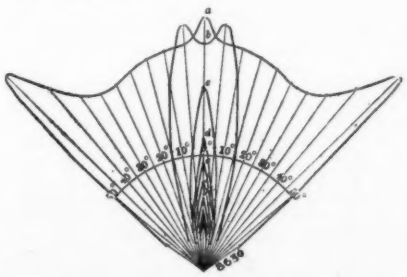


FIG. 5.—VELOCITY OF AIR FROM FAN D.

TABLE VI.—TESTS OF ELECTRIC PROPELLER FANS.

Fan.	Type.	Total air delivered.	Cubic feet of air per watt.	Cubic feet of air per net watt.	Cubic feet of air per net watt at uniform speed of 1,600 revolutions.
A	Direct current	1215 cubic feet per min.	27·2	52·6	72·4
B	,, ,,	1053 ,, ,,	22·1	65·5	54·7
C	,, ,,	1155 ,, ,,	24·2	55·	58·2
D	Alternating current	878 ,, ,,	24·4	77·	85·3
E	,, ,,	837 ,, ,,	12·5	80·5	78·9
F	,, ,,	537 ,, ,,	9·3	22·7	52·2
G	,, ,,	937 ,, ,,	24·	62·4	69·5

TABLE VII.

——	A.	B.	C.	D.	E.	F.	G.
Length of blade	5·19	5·4	5·35	5·6	5·4	5·4	5·7 in.
Diameter of fan	11·53	12	12	12·4	12	11·8	12¼ in.
Total area of all blades	50·18	51·36	51·12	59·78	51·16	50·7	50·5 sq. in.
Radius of curvature	15·25	6·98	6·6	12·5	19·8	8·1	7·1 in.

Figs. 4 and 5 show the velocity of the air from fans *A* and *D*, curve *a* being the velocity 6 in. from the fan, curve *b* 2 ft. 6 in., curve *f* 10 ft. 6 in. from the fan. The velocity in feet per minute, 6 in. from the centre of the fan on fan *A* is 1195, and fan *D* 930.

Concrete for Battleship Protection.—Many proposals have been made to provide some cheaper substitute for armour plating for the protection of battleships from gun fire, but perhaps the best of these is that of an Italian engineer, Signor d'Adda, who suggests using reinforced concrete for this purpose. The concrete is placed between two metal plates, so as to be closed and compressed between two iron or steel walls of variable thickness which on the impact of projectiles prevent deformation of concrete. The two metal walls are reinforced by metal ribs or transverse ties, and, if desired, vertical ribs or ties with interposed transverse plates. According to the *Practical Engineer*, Signor d'Adda's protecting concrete comprises in variable proportions hydraulic lime, cements, Portland cements, puzzolanes, calcareous sands and silicious sands, gravel, and stone fragments. A highly shot-resisting and preferred mixture comprises very fine Portland cement, silicious sand, river stones, minute or fractured calcareous stone. These ingredients may be combined together in varying proportions according to the degree of resistance proposed.

A very high resistance may be obtained with the following preferred composition: Portland cement 1 vol., silicious river sand 1½ vol., and calcareous stone fragments 4 vol. By increasing the proportion of cement and correspondingly diminishing that of sand and scale, a yet harder and more resistant concrete may be obtained, but its specific weight also will be proportionately increased, so that it will be seen that an excessively hard concrete is not always the most suitable concrete for the purpose. One of the main features of the invention is a method of applying the concrete in layers of progressively increasing hardness. Suppose the armour has a thickness of 5 ft. of concrete, this is subdivided into two or more vertical zones, separated from each other by metal plates or wire network, between which concrete of different degrees of hardness is filled in, so that the hardest and heaviest layer will be in contact with the outer metal wall of the armour and the other zones are formed with concrete layers of a hardness and a weight progressively decreasing towards the interior metal wall of the armour, thus being applied to concrete armours the very principle of progressive case hardening used for steel armours.

Repairs done under the Sea.—Mr. J. Sandeman Allen, the chairman of the Liverpool Salvage Association, referred at the annual meeting of the association to a feat which, he said, made a record in salvage work. It was the case of the steamer *Veronese*, which, with a valuable cargo, sank with a hole in her bow. The question was whether the old method of discharging the cargo and patching the vessel from the inside would have to be adopted, or whether it could be avoided. It was decided to repair the damage under water, utilising pneumatic tools which have recently come into use. Divers took the measure of the damage, and a steel patch was made on board the salvage steamer. Working on a platform 28 feet below water, divers drilled the necessary holes in the ship. The plate was then sent down and fixed at once by patent bolts invented by the Association's surveyor. The cargo was not disturbed, and the ship was brought back to Liverpool through the Bay of Biscay, in variable weather, without starting a leak.

In this section is presented every month a list of the more important articles appearing in the Engineering Press and of the leading papers read before the various engineering institutions. Full names, addresses, and published prices of the publications indexed are printed each half-year in the volume index.

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Strengthening a Double Line Railway Bridge. *Engineer*, 20*th March*, 1908.

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